(12)

B.S.

NUSC Technical Report 4979

ADA024462

Summary of a One-Year Ambient Noise Measurement Program Off Bermuda

ANTHONY J. PERRONE
Ocean Sciences and Technology Department

1 April 1976

NAVAL UNDERWATER SYSTEMS CENTER
New London Laboratory

Approved for public release; distribution unlimited.

PREFACE

The work described in this report was accomplished under NUSC Project No. A-650-05, Navy Subproject No. SF 52 552 702, Task No. 118286, "Ambient Noise Characteristics Affecting Sonar and Physical Oceanography," Principal Investigator, R. L. Martin (Code TA112). The Sponsoring Activity was Naval Sea Systems Command, Program Manager, A. Franceschetti (Code SEA 06H1).

The Technical Reviewer was R. L. Martin (Code TA112).

REVIEWED AND APPROVED: 1 April 1976

R. W. Hasse
Associate Director for Sonar Research

The author of this report is located at the New London Laboratory, Naval Underwater Systems Center, New London, Connecticut 06320.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) NUSC-TR-4979	2. GOVT ACCESSION NO. (9) Technical rept.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) SUMMARY OF A ONE-YEAR AMBIENT NOISE MEASUREMENT PROGRAM OFF BERMUDA.		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Anthony J. Perrone		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Underwater Systems Center New London Laboratory New London, CT 06320		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS A-650-05 SF 52 552 702 118286
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command SEA 06H1 Washington, DC 20362		12. REPORT DATE (11) 1 April 1976
		13. NUMBER OF PAGES 46 (12) 75p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (16) SF52-552, NUSC-A-650-05		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(17) SF52-552-702

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ambient Noise Levels	Frequency Dependence
Autocorrelation	Standard Deviation
Crosscorrelation	Wind Dependence
Depth Dependence	Zero-Axis Crossing Times

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of ambient noise data recorded simultaneously during a one year period between January and December 1966 from 5 hydrophones located in the Northwest Atlantic at depths of 30, 400, 1100, 2400, and 2500 fm (55, 730, 2000, 4400, and 4500 m) are presented. The results show a dependence in the ambient noise spectrum levels as a function of depth, frequency, and wind speed.

The shallow hydrophone (at 30 fm or 55 m) was more wind dependent than the

next pg

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

405 918

20. (Cont'd)

deeper ones, especially at frequencies below 281 Hz. Above 281 Hz, the correlation coefficient of the ambient noise spectrum levels with wind speed is observed to be essentially independent of water depth for all 5 hydrophones. No significant seasonal effects on the mean values of the ambient noise levels is observed as a function of depth, except for differences in level caused by the wind speed conditions existing during the different seasons.

The difference in ambient noise level between hydrophone depths as a function of frequency is suspected to be the result of the two major directional noise sources existing in deep ocean areas. One of these noise sources yields a signal that arrives from a nearly vertical direction and is generated by local wind speed conditions that affect the frequency range above 177 Hz, where ambient noise spectrum levels decrease with increasing depth. The other noise source yields a signal that arrives from the horizontal direction and is generated by long distance shipping; this source affects the frequency range below 177 Hz. The ambient noise signals in this range arrive at the receiver via the RSR and RRR paths. The results obtained from the autocorrelation of the ambient noise data for each logit band between 11 and 1414 Hz indicates that there are two zero-axis crossing times for the autocorrelation function versus frequency. One zone, above 212 Hz, shows an average zero axis crossing time of 30 hr (wind dependent zone) and the other, below 141 Hz, has zero-axis crossing times of approximately 12 hr (shipping dependent zone).

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

SUMMARY OF A ONE-YEAR AMBIENT NOISE MEASUREMENT PROGRAM OFF BERMUDA

I. INTRODUCTION

The results presented in this report were obtained during a one-year ambient noise measurement program conducted at the Tudor Hill Laboratory in Bermuda between January and December 1966. The measurements were made to obtain basic information regarding simultaneously recorded ambient noise spectra levels in the deep ocean as a function of hydrophone depth, hydrophone location (i.e., bottom mounted or suspended), hydrophone separation, environmental conditions, and seasonal variations. The acoustic data were obtained from 5 omnidirectional hydrophones selected from among various arrays cabled to the Tudor Hill Laboratory (see figure 1).* The depth of the hydrophones (figure 2) ranged from 30 to 2500 fm (55 to 4500 m).

DATA RECORDING

The ambient noise signals from each of the hydrophones were automatically recorded simultaneously every 2 hr for 2 min periods. A total of 12 samples per day were recorded on a 10 in. (25.4 cm) reel of magnetic tape (beginning at 1000 one day and ending at 0800 the following day). The ambient noise levels from these hydrophones were recorded on a 7 track 0.5 in. (1.27 cm) magnetic tape recorder operating at a tape speed of 15 in./sec (38 cm/sec). Channels 1 through 5 were used in the FM mode for data signals only and channel 6 was used in the direct mode (primarily for data sample time identification and voice commentary). A Hyperion time code generator signal (IRIG Code "B" in the 1 sec time frame) was recorded on channel 6 as the time base. Wind speed and wave height data were recorded, simultaneously with the acoustic data, from a location in the area of the hydrophones. The wind speed and wave height data were obtained from an anemometer and wavestaff system located on Argus Island (a fixed platform in the open ocean). The anemometer was 150 ft (46 m) above the sea surface.

In addition to the instrumentation used for data recording, a visual monitoring system was provided to establish the presence of contaminating ship noise or other man-made noises. The system provided a sequential on-line copy of each hydrophone output through a bank of logit filters (see the block diagram shown in figure 3).† The

*Figures first referenced in a section are presented at the end of that section.

†Logit filters have a band ratio defined by $10 \log f_2/f_1 = 1$, which is essentially the same as for 1/3-octave filters (i.e., $10 \log 2^{1/3} \approx 1$). However, center frequencies for the logit filters are at the upper bandedge of conventianal 1/3-octave filters.

ambient noise signal from each hydrophone output was sequentially scanned once every 2 hr for 2 min periods. The output of the scanner was then fed to a bank of 7 logit filters centered at 11, 22, 56, 141, 354, 891, and 1414 Hz. The signal level from the output of each filter was then fed to 7 channels of an 8 channel Sanborn Tape Recorder. A fluctuating direct current signal representing the wind speed level measured by an anemometer located on a fixed platform in the vicinity of the hydrophones was recorded on channel 8. A marker channel located at the edge of the Sanborn paper was activated each time the recorder was operating in the record mode. Consequently, for all the ambient noise samples on tape, there is a corresponding Sanborn trace of one complete scan cycle containing the sequential on-line levels of each hydrophone output. In essence, the traces represent a daily log that was frequently referred to in editing the recorded ambient noise samples during reduction of the taped data.

CALIBRATION

System calibration and noise samples were recorded on magnetic tape on a weekly basis during the one year period. Calibration of all signal channels was performed in parallel using center frequency sine wave signals for each logit filter band ranging from 11 to 1414 Hz. Various calibration measurements during the year indicated that system gain was maintained to within 1 dB.

DATA PROCESSING

For each 2 min record of ambient noise, the data processing system[1] computed the mean value of one hundred 1 sec RMS levels in each of the logit filter bands for the 11 to 1414 Hz range. Records exhibiting high levels attributable to biological noise, identifiable local shipping, or other man-made noises were discarded. The single wind speed value associated with each 2 min ambient noise record was determined by averaging the wind speed over a time interval of from approximately 12 min before the ambient noise record to approximately 12 min after. Wave height values were determined in the same manner.

[1] E. P. Kelley, Data Processing at the U.S. Navy Underwater Sound Laboratory, NUSL Technical Report 568, 22 January 1963.

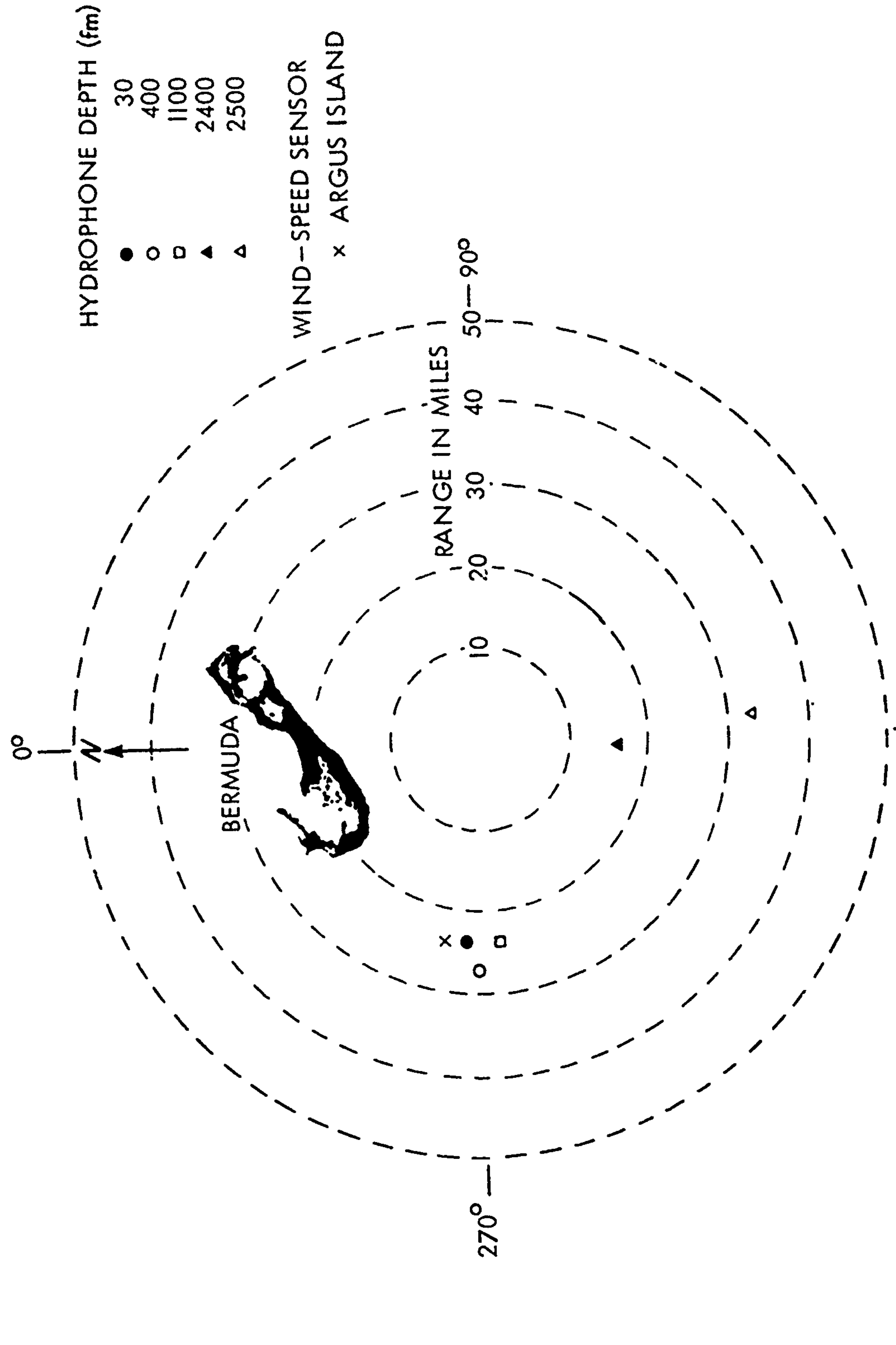


Figure 1. Hydrophone and Wind Speed Sensor Locations

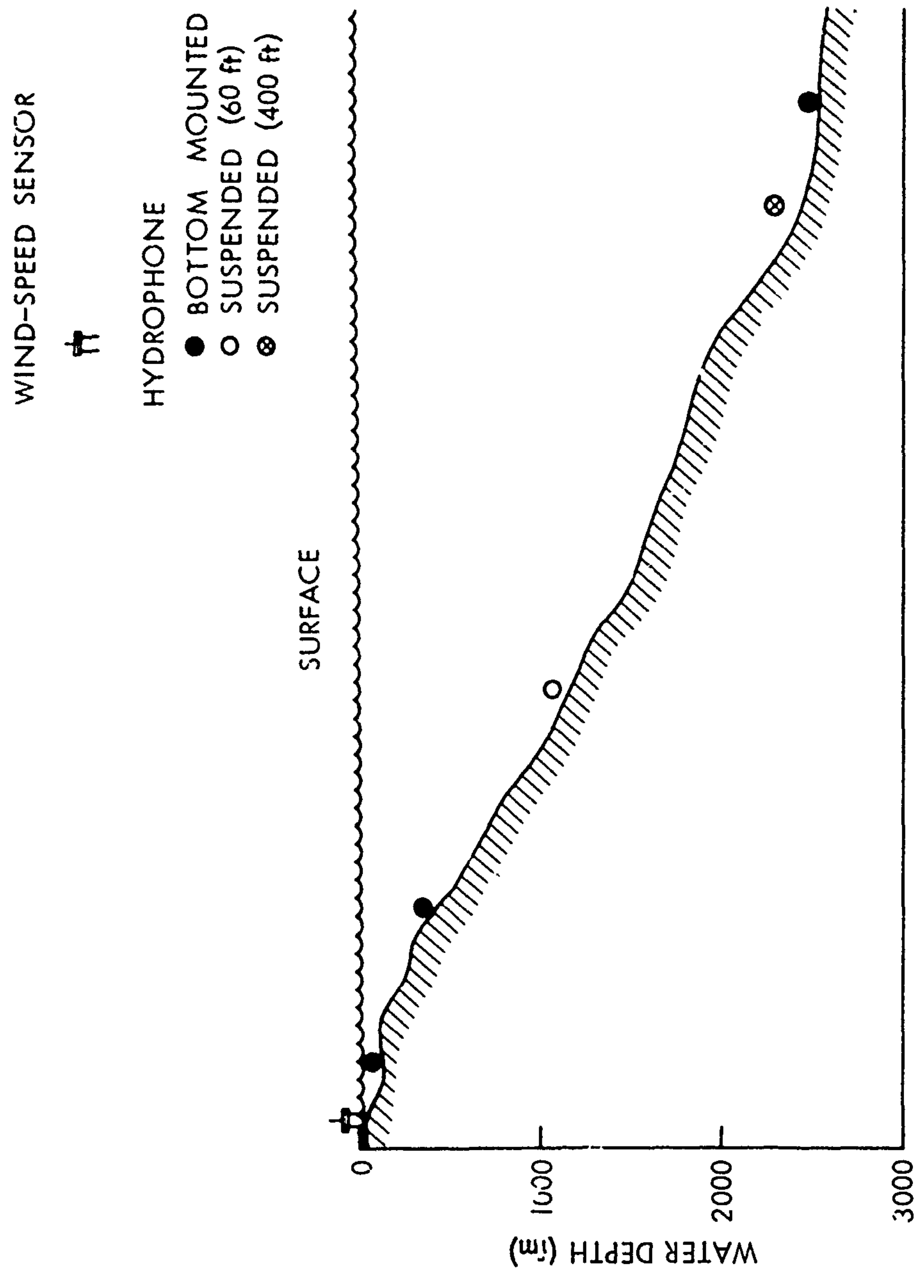


Figure 2. Hydrophone Depths

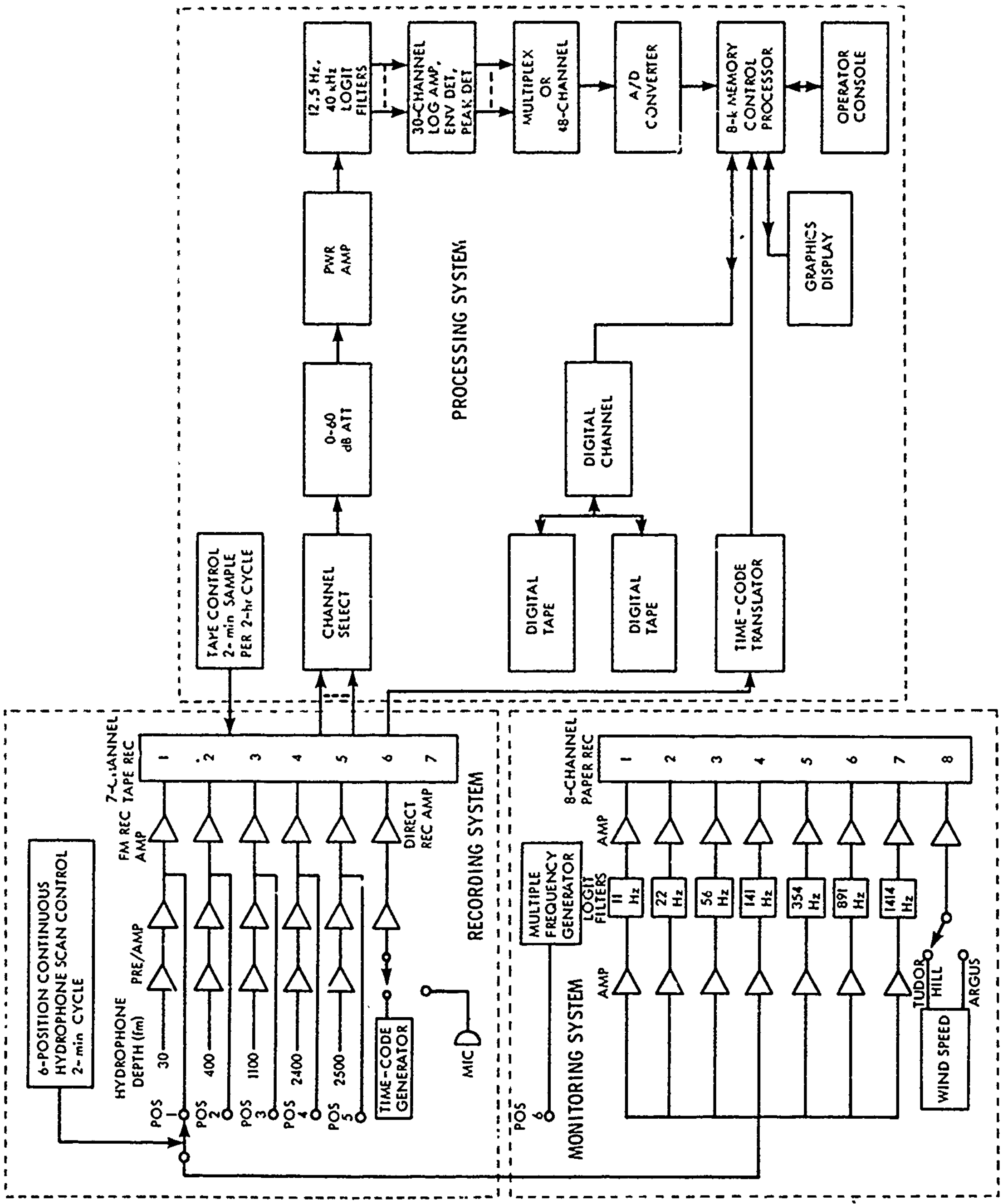


Figure 3. Measurement/Monitoring and Processing System

II. COMPARISON OF AMBIENT NOISE AND WIND SPEED VERSUS TIME

Monthly variations of the ambient noise level for data recorded from the 2400 fm (4400 m) hydrophone for each filter band from 11.2 to 2816.0 Hz are shown in figure 4 for the entire year. The curve at the bottom of the figure represents the corresponding monthly wind speed variations. The wide fluctuation of wind speed, especially for the winter months, is typical of the Bermuda area.[2] Wind speeds as high as 50 knots and as low as 0 knots are observed on several occasions and the following qualitative conclusions may be drawn:

- The ambient noise level curves shown between 141 and 1414 Hz bear a striking resemblance to the wind speed curve, indicating a strong wind dependence in the upper frequency bands. The dependence appears to decrease with decreasing frequency.
- Very little wind dependence is apparent for the curves between the 17 and 112 Hz bands, except at very high wind velocities.
- Wind dependence is observed in the two lowest bands (center frequencies at 11 and 14 Hz), although to a lesser degree than in the higher bands.

[2] A. J. Perrone, "Deep-Ocean Ambient Noise Spectra in the Northwest Atlantic," Journal of the Acoustical Society of America, vol. 46, 1969, pp. 672-770.

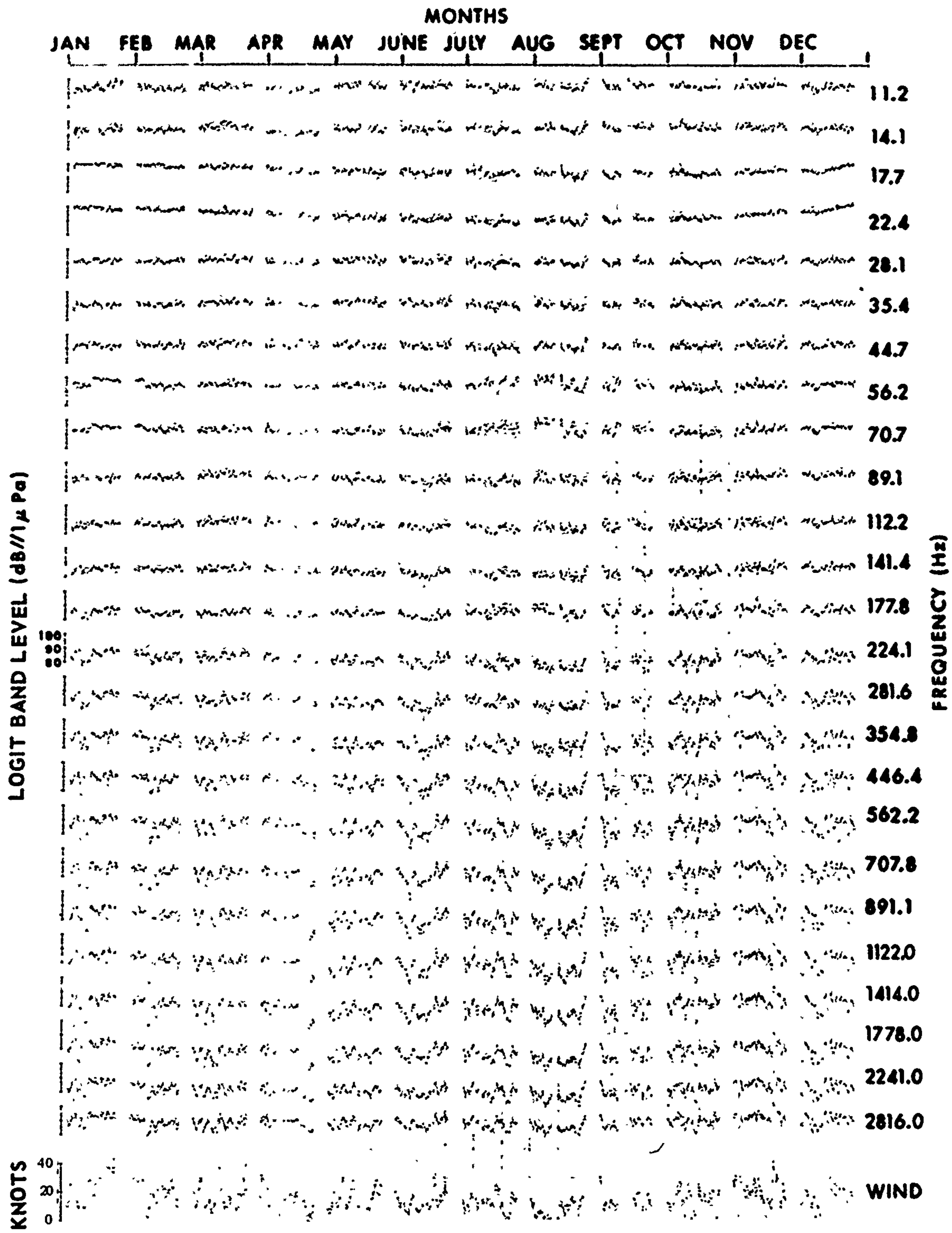


Figure 4. Comparison of Logit Filter Ambient Noise Level and Wind Speed Variation Versus Time for One Year

III. MONTHLY AMBIENT NOISE SPECTRA AND MEDIAN VALUES VERSUS HYDROPHONE DEPTH

The data in figure 5 are grouped according to wind speed, and the mean spectrum level is plotted versus frequency for eight 5 knot wind speed groups and for each of the 5 hydrophone depths. The spectra for each hydrophone depth are plotted on a month-to-month basis to display the monthly variation in the ambient noise spectra and any variations occurring as a function of depth. *

Also shown in figure 5 are a

1. yearly summary of ambient noise spectra and system noise curve (denoted by the shaded area) for each hydrophone depth based on the combined 12 month data;

2. histogram illustrating the total number of 2 min ambient noise samples contained in the yearly spectra for each hydrophone and for each of the eight 5 knot wind speed groups; and

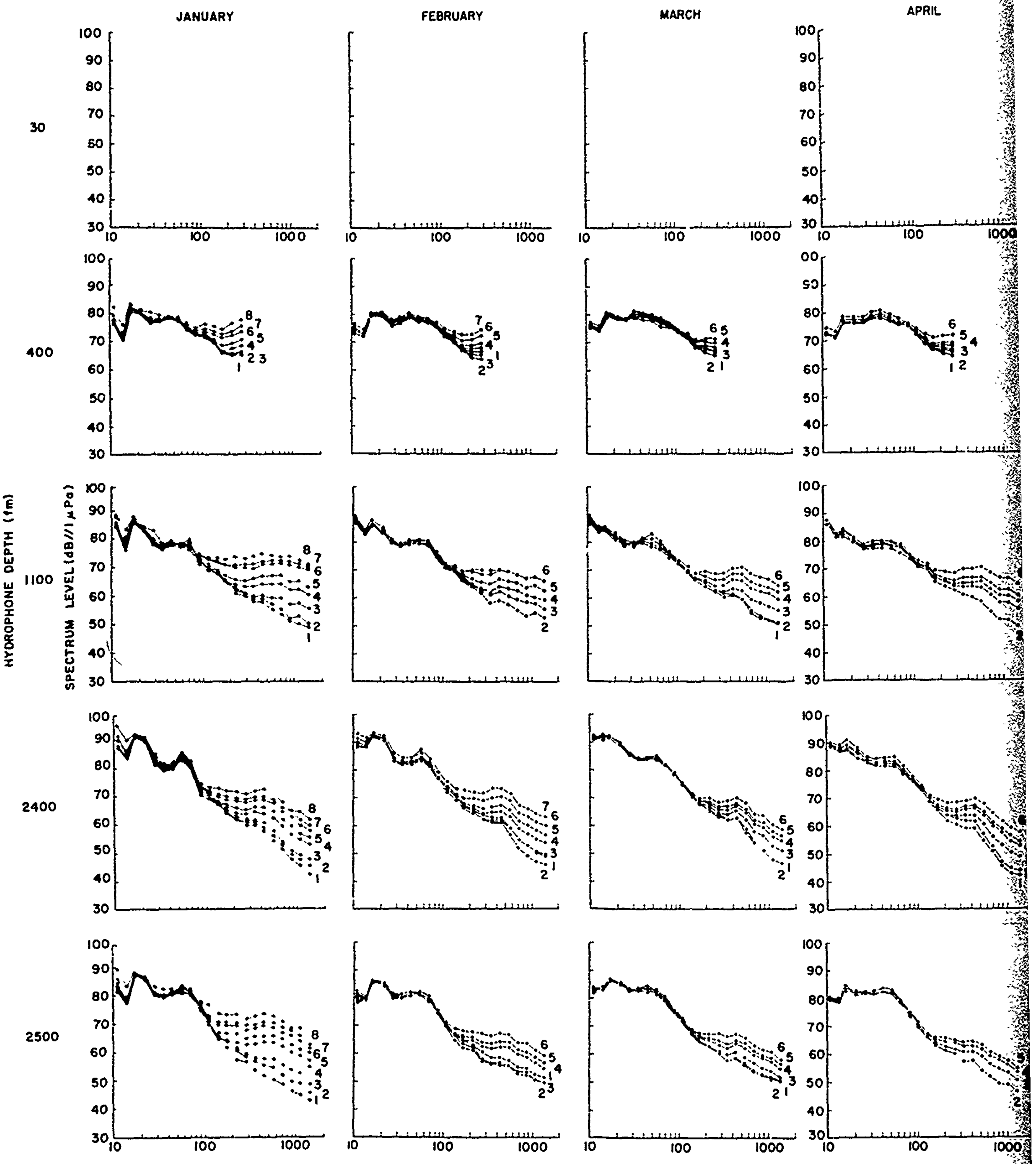
3. tabulation of the 2 min samples on a month-to-month basis for each wind speed group and hydrophone depth.

Figure 6 shows the month-to-month and yearly summary of median ambient noise spectra levels for each logit frequency band together with the upper and lower quartile values(denoted by the vertical lines) for the 5 hydrophone depths. The month-to-month median ambient noise values are replotted in figure 7 for each logit band of frequencies ranging from 11 to 1414 Hz and for each hydrophone depth against month-to-month median wind speed values for the entire year.

A comparison of the curves in figure 7 shows a striking similarity in the shapes of the median ambient noise curves for the year and the shapes of the median wind speed curves for corresponding periods. This is especially true above 224 Hz for hydrophones at depths greater than 400 fm (730 m) and above 89 Hz for the 30 fm (55 m) hydrophone. The yearly wind speed pattern is observed to a lesser degree in the median ambient noise curve below 224 Hz, except at 17, 22, 112, and 141 Hz. In the two lower bands, 17 and 22 Hz, the apparent similarity between the yearly wind speed patterns and the median ambient noise curves is suspected to be biological noise generated by the so-called "20-Hz monster" because the spectra curves in figure 5 show little or no wind speed dependence at these frequencies. In additon, the spectra curves for individual months show a peak around 20 Hz that is greater in the winter months; little or no peaking is observed to exist in the summer months. Seasonal variations in the ambient noise spectra for different depths versus frequency are shown in figure 8. The median ambient noise spectra for each hydrophone depth are plotted for all ambient data recorded during January, April, July, and October* for all data independent of wind speed conditions and for data recorded only during periods when wind velocities were between 18 and 22 knots. This was done to isolate variations

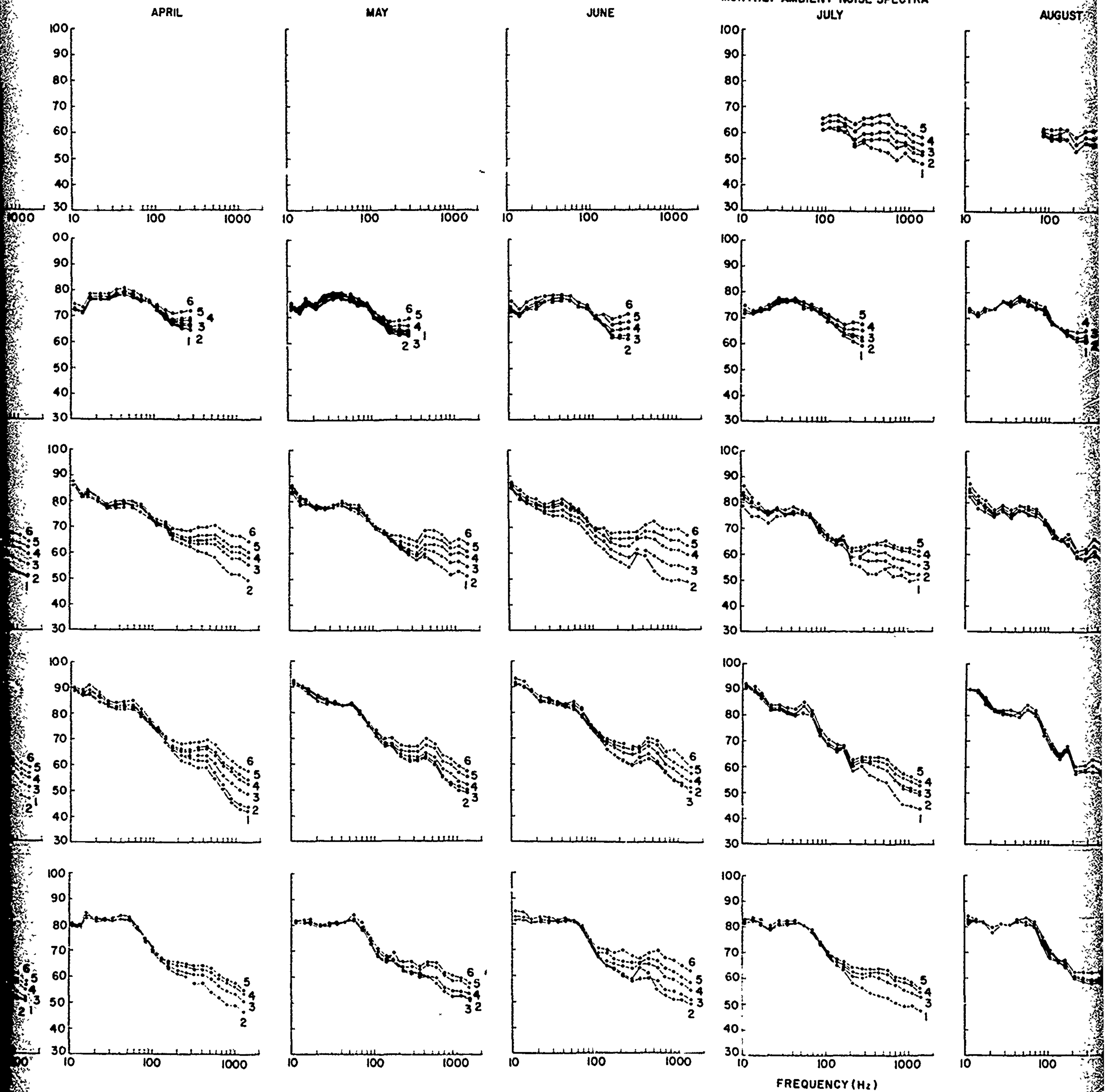
*Data from the 30 fm (50 m) hydrophone were not available until July.

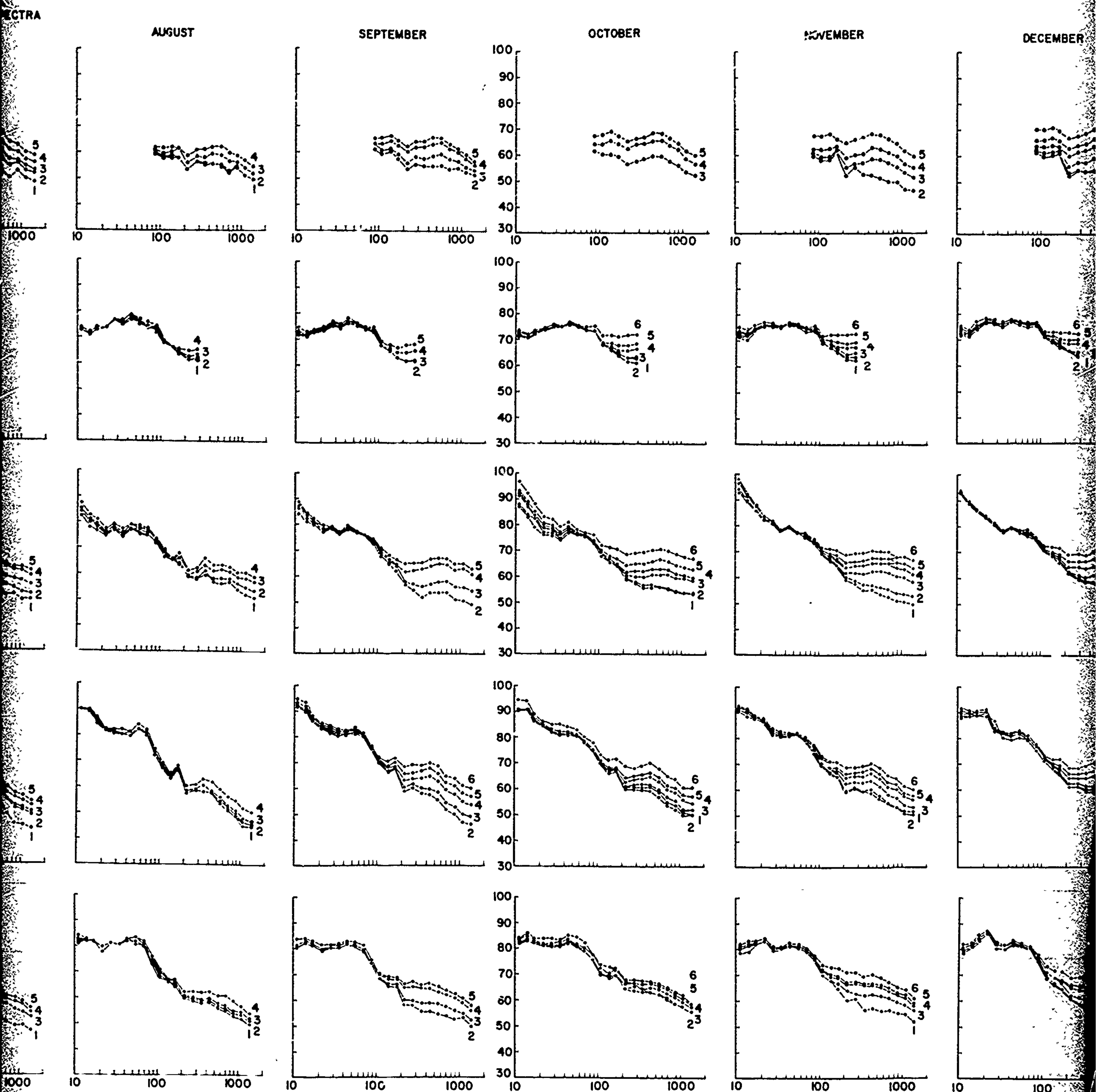
in the spectra that were the result of different wind speed distributions for each of the months from seasonal variations caused by factors that are not so readily meassurable. There is no significant change in spectra level for a given hydrophone depth as a function of season, except those caused by the different wind speed conditions. The median ambient noise levels for each of the four months (for all data independent of wind speed) were replotted in figure 9 versus frequency, using hydrophone depth as the parameter. The difference in the spectra levels as a function of depth are essentially the same and independent of season.



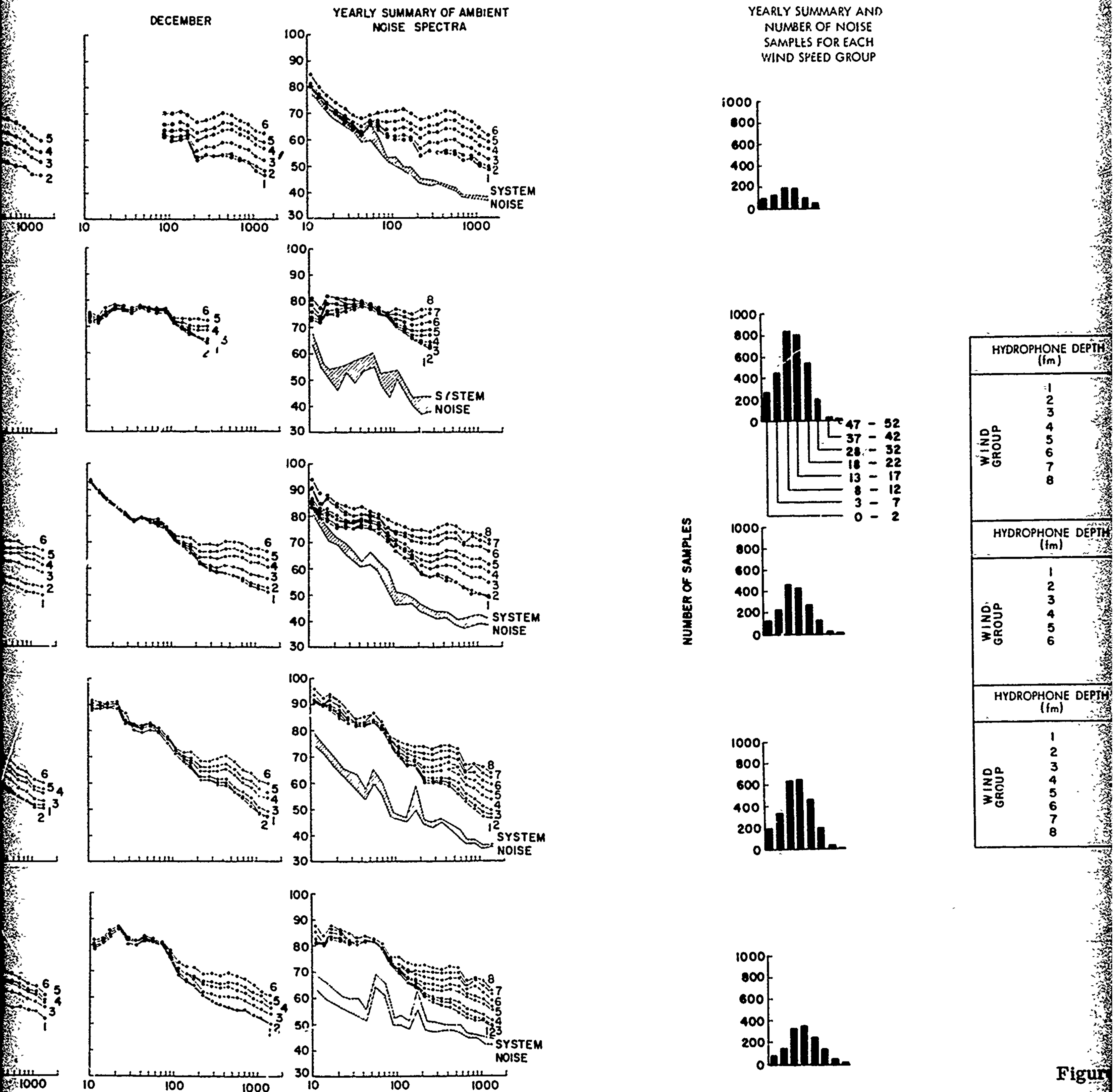
JANUARY
FEBRUARY
MARCH
APRIL
HYDROPHONE DEPTH (fm)
SPECTRUM LEVEL (dB//1 μPa)
30
400
1100
2400
2500
100
90
80
70
60
50
40
30
10
100
1000

MONTHLY AMBIENT NOISE SPECTRA




ECTRA
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
100
90
80
70
60
50
40
30
10
100
1000

3

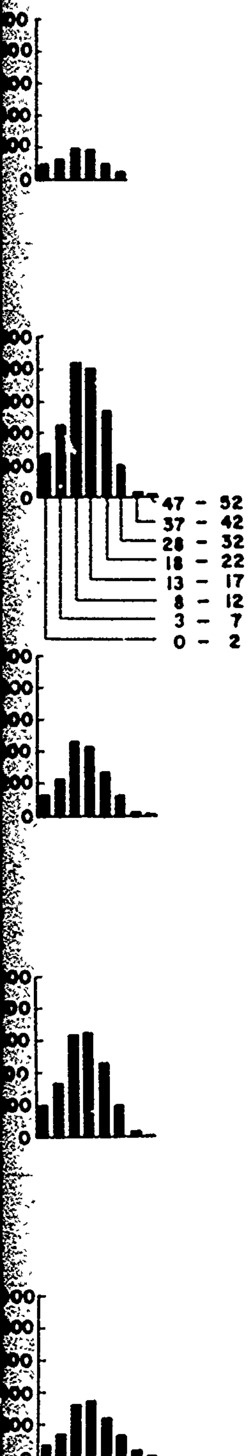


DECEMBER
YEARLY SUMMARY OF AMBIENT NOISE SPECTRA
YEARLY SUMMARY AND NUMBER OF NOISE SAMPLES FOR EACH WIND SPEED GROUP
NUMBER OF SAMPLES
SYSTEM NOISE
47 - 52
37 - 42
28 - 32
18 - 22
13 - 17
8 - 12
3 - 7
0 - 2
HYDROPHONE DEPTH (fm)
WIND GROUP

Figur

4

YEARLY SUMMARY AND NUMBER OF NOISE SAMPLES FOR EACH WIND SPEED GROUP



NUMBER OF 2 MINUTE SAMPLES PER WIND SPEED GROUP

HYDROPHONE DEPTH (fm)	JANUARY 30	JANUARY 400	JANUARY 1100	JANUARY 2400	JANUARY 2500	FEBRUARY 30	FEBRUARY 400	FEBRUARY 1100	FEBRUARY 2400	FEBRUARY 2500	MARCH 30	MARCH 400	MARCH 1100	MARCH 2400	MARCH 2500
WIND GROUP 1		5	5	5	5		10		7	6		17	9	13	5
2		14	8	10	12		14	5	10	7		46	81	29	13
3		50	42	41	39		25	13	18	11		75	61	60	35
4		34	26	30	31		64	35	51	17		88	73	69	31
5		36	17	35	33		61	39	53	23		53	48	52	29
6		41	29	42	41		53	12	48	28		29	15	26	8
7		22	13	21	21		6		5						
8		6	3	6	5										

HYDROPHONE DEPTH (fm)	APRIL 30	APRIL 400	APRIL 1100	APRIL 2400	APRIL 2500	MAY 30	MAY 400	MAY 1100	MAY 2400	MAY 2500	JUNE 30	JUNE 400	JUNE 1100	JUNE 2400	JUNE 2500
WIND GROUP 1		19		9			10	7							
2		51	[illegible]	21	11		25	16	18	12		58	51	42	19
3		32	[illegible]	14	6		107	84	72	37		95	96	73	39
4		67	34	34	27		67	61	45	28		68	66	56	19
5		53	37	30	18		54	55	42	15		48	46	41	28
6		19	19	15			19	16	18	5		7	7	7	5
7															
8															

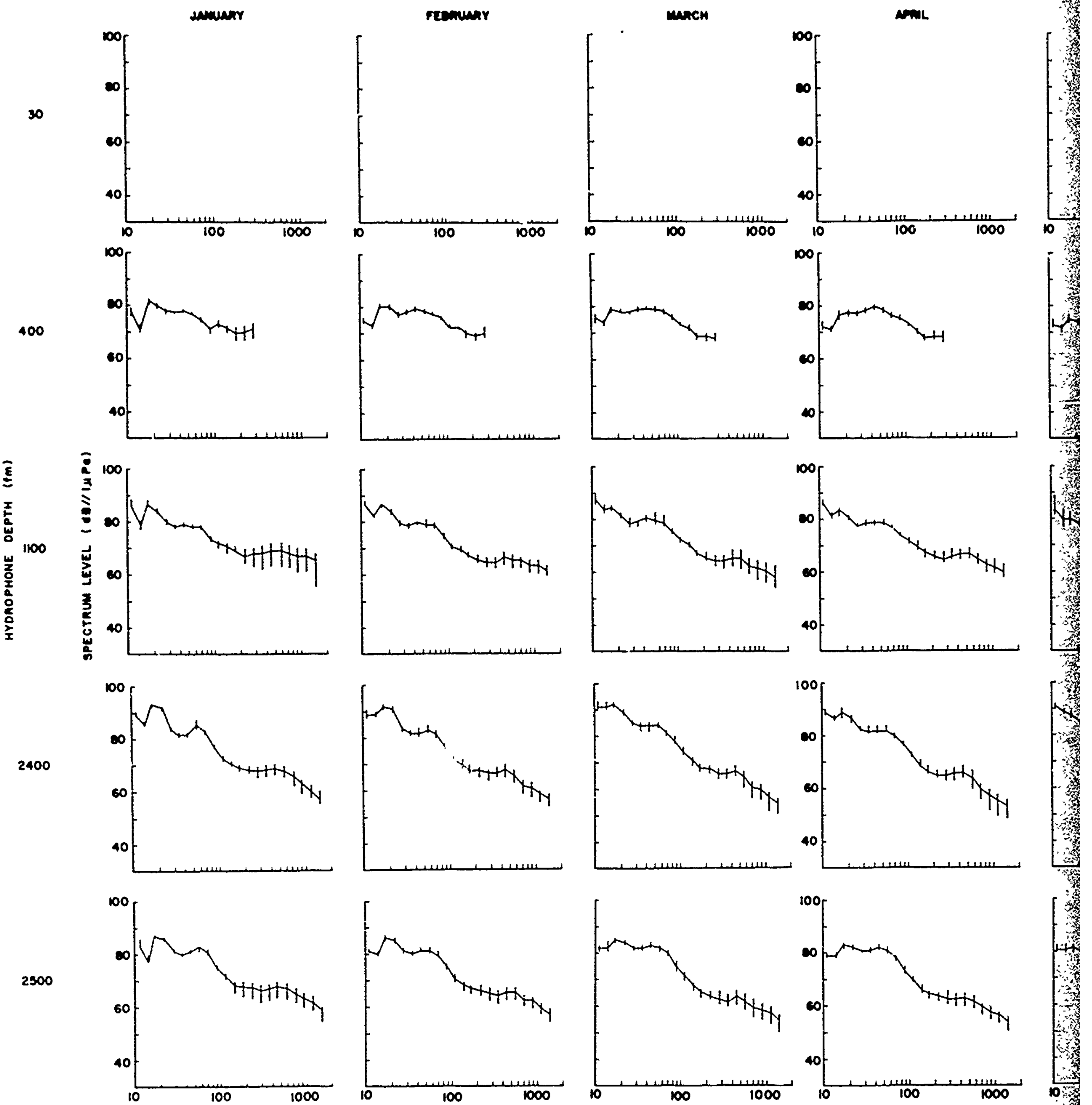
HYDROPHONE DEPTH (fm)	JULY 30	JULY 400	JULY 1100	JULY 2400	JULY 2500	AUGUST 30	AUGUST 400	AUGUST 1100	AUGUST 2400	AUGUST 2500	SEPTEMBER 30	SEPTEMBER 400	SEPTEMBER 1100	SEPTEMBER 2400	SEPTEMBER 2500
WIND GROUP 1	12	34	32	24	12	52	87	57	69	13					
2	26	33	26	32		33	61	50	58	17	14	49	10	40	12
3	51	104	95	80	42	36	79	47	78	35	45	96	28	66	29
4	45	93	90	79	39	23	39	17	42	15	20	58	20	44	22
5	8	30	16	26	14						6	19	7	12	7
6														5	

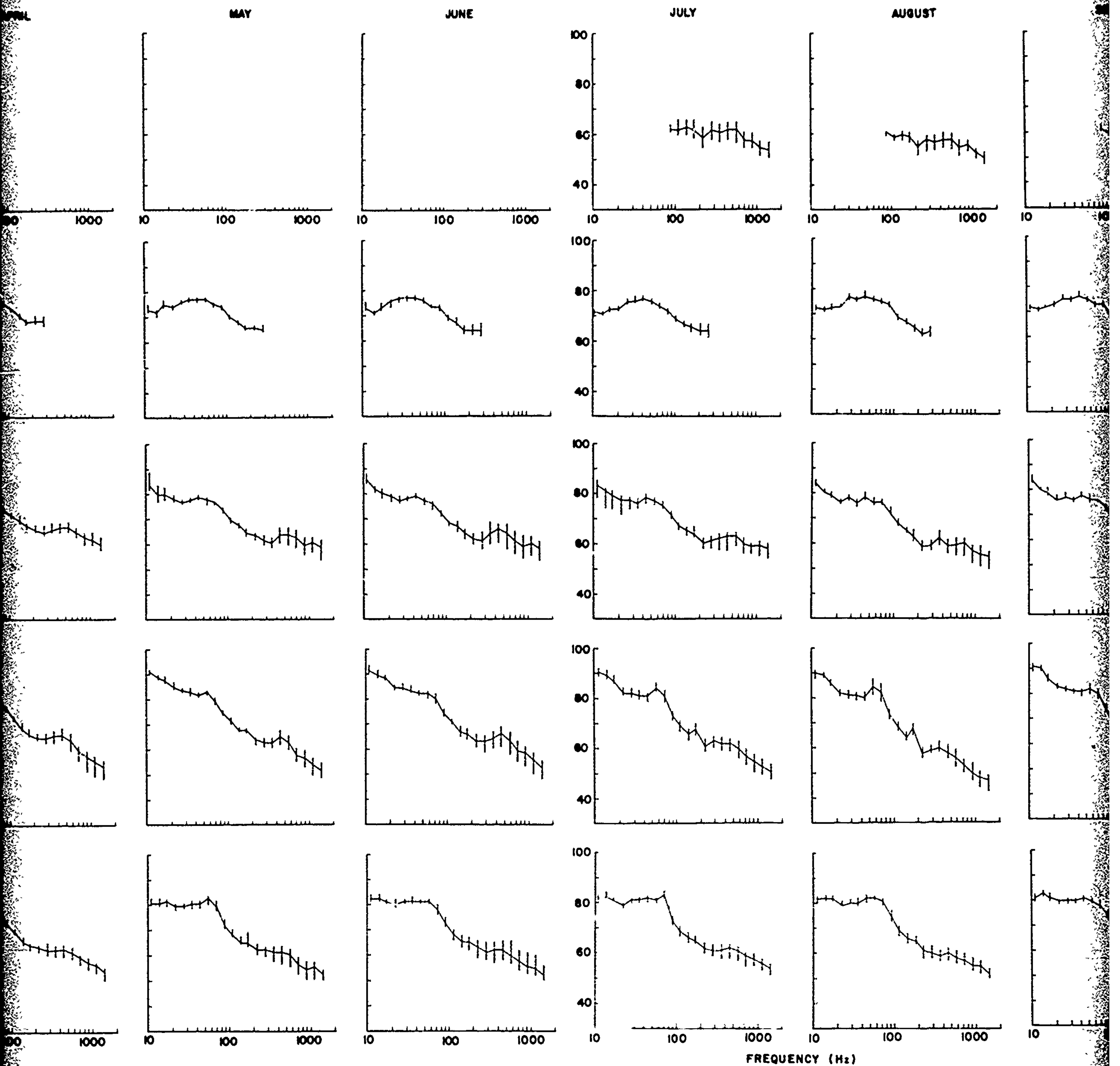
HYDROPHONE DEPTH (fm)	OCTOBER 30	OCTOBER 400	OCTOBER 1100	OCTOBER 2400	OCTOBER 2500	NOVEMBER 30	NOVEMBER 400	NOVEMBER 1100	NOVEMBER 2400	NOVEMBER 2500	DECEMBER 30	DECEMBER 400	DECEMBER 1100	DECEMBER 2400	DECEMBER 2500
WIND GROUP 1		41	36	36			12	6	7	5	28	24	17	19	10
2		28	24	19	7	6	12	12	13		52	56	48	41	18
3	13	69	62	59	30	5	40	35	38	10	44	47	38	38	9
4	12	84	79	79	50	5	72	47	63	34	67	71	56	63	32
5	17	58	55	52	21	8	75	55	61	32	50	53	43	52	16
6		5	5	5	5		12	11	11	5	13	12	14	14	7

HYDROPHONE DEPTH (fm)	YEAR 30	YEAR 400	YEAR 1100	YEAR 2400	YEAR 2500
WIND GROUP 1	99	264	130	192	65
2	135	447	228	333	134
3	197	817	464	637	322
4	188	805	431	655	345
5	103	541	272	458	237
6	19	203	132	195	114
7		34	23	32	29
8		6	3	6	5

WIND GROUP	WIND SPEED (knots)
1	0-2
2	3-7
3	8-12
4	13-17
5	18-22
6	28-32
7	37-42
8	47-52

Figure 5. Monthly and Yearly Ambient Noise Spectra for 5 Hydrophone Depths


JANUARY
FEBRUARY
MARCH
APRIL
HYDROPHONE DEPTH (fm)
30
400
1100
2400
2500
SPECTRUM LEVEL (dB//1μPa)
100
80
60
40
10
100
1000



MAY
JUNE
JULY
AUGUST
100
80
60
40
10
100
1000
FREQUENCY (Hz)

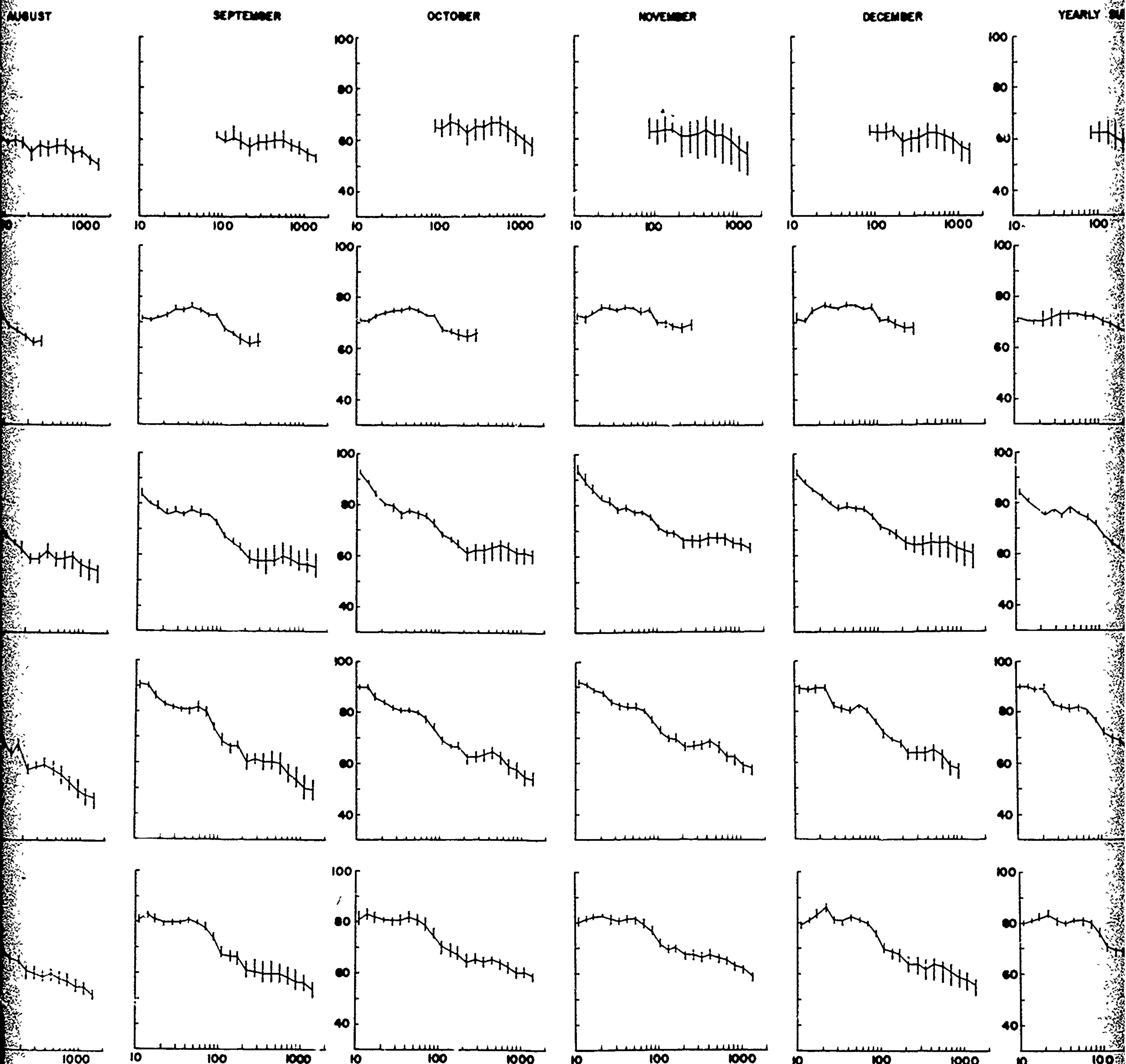


Figure 6. Monthly and Yearly Median Values of Ambient Noise Sho
Upper and Lower Quartile Values for 5 Hydrophone Depths

3

REVE

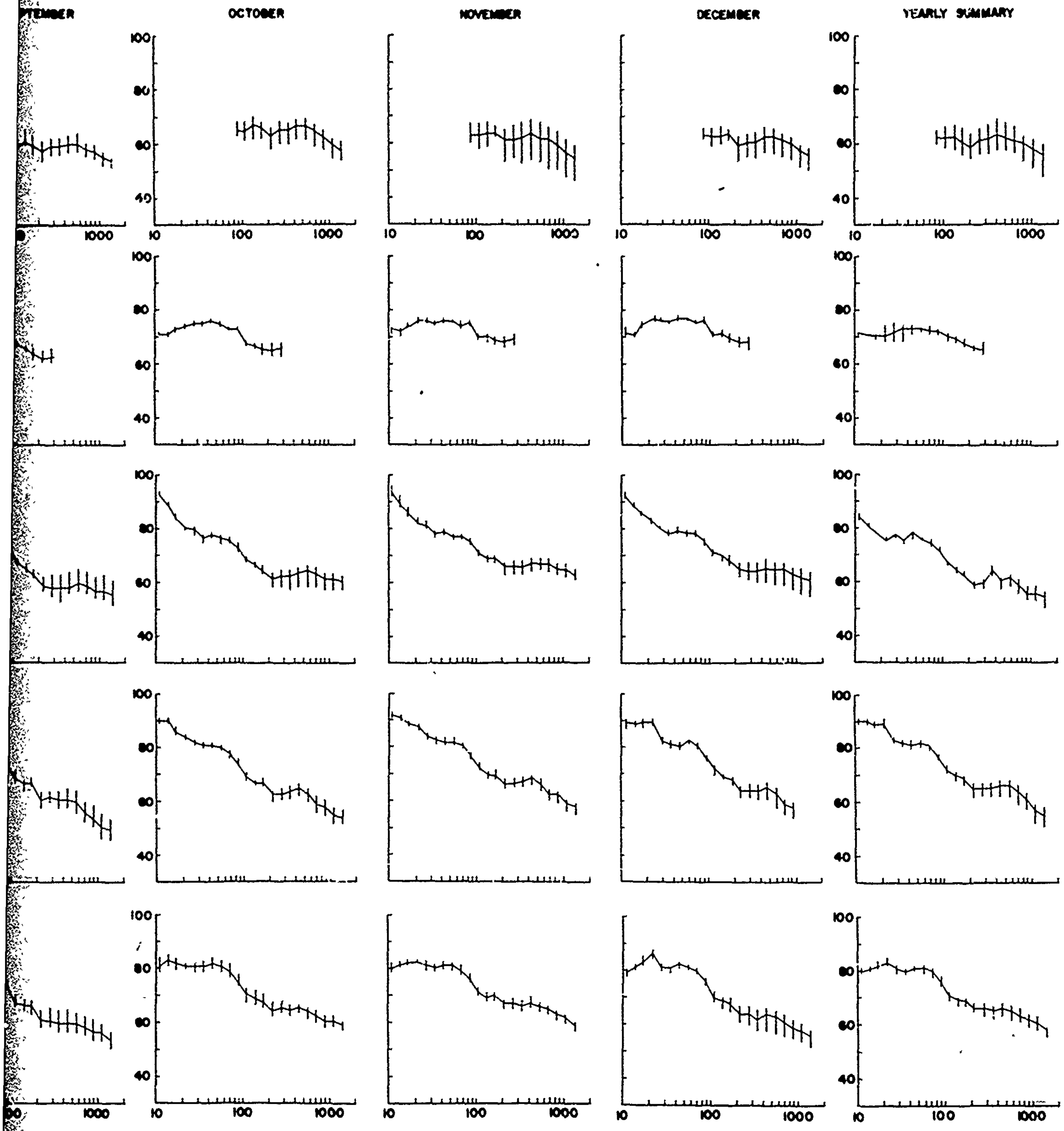
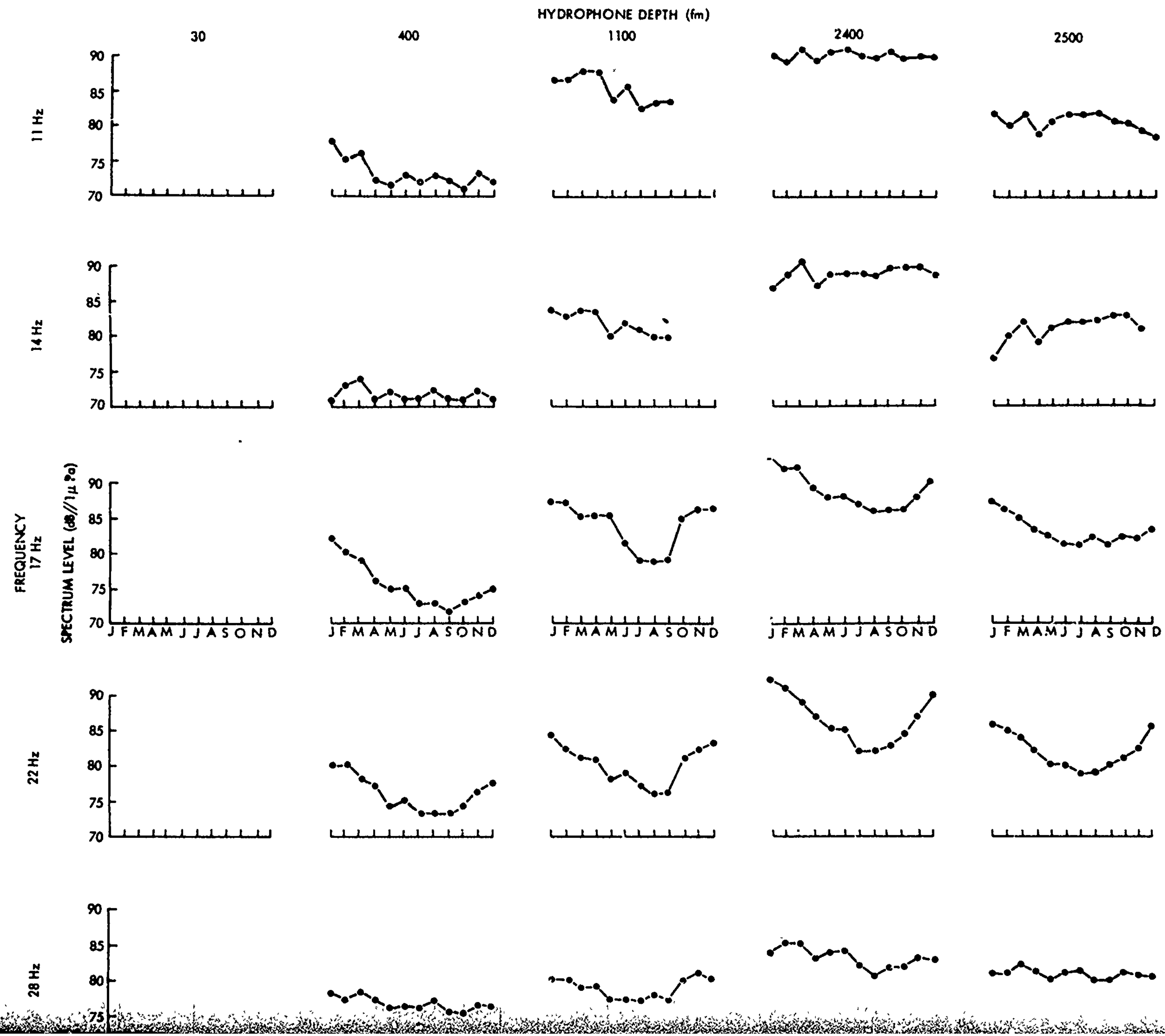
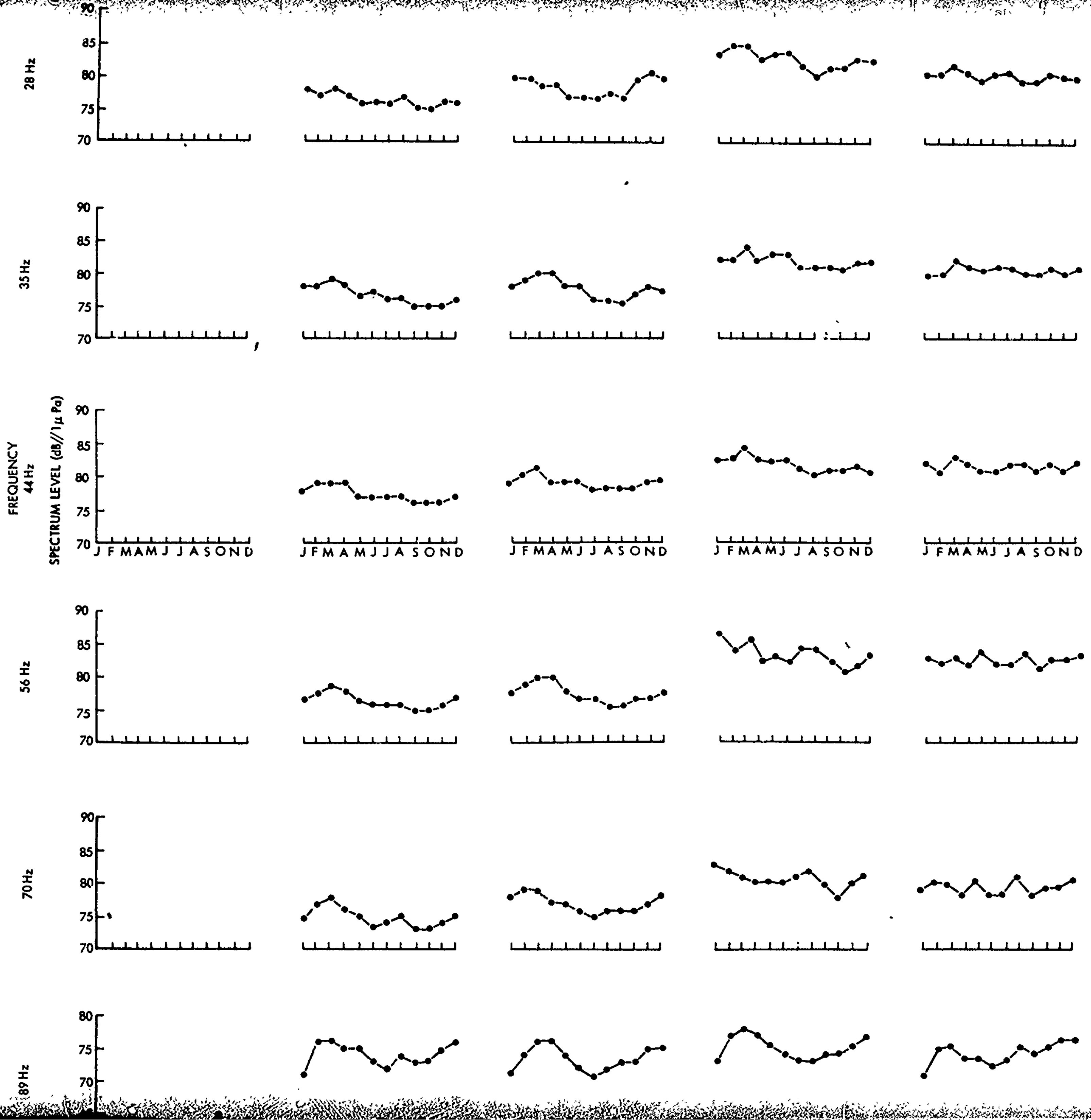


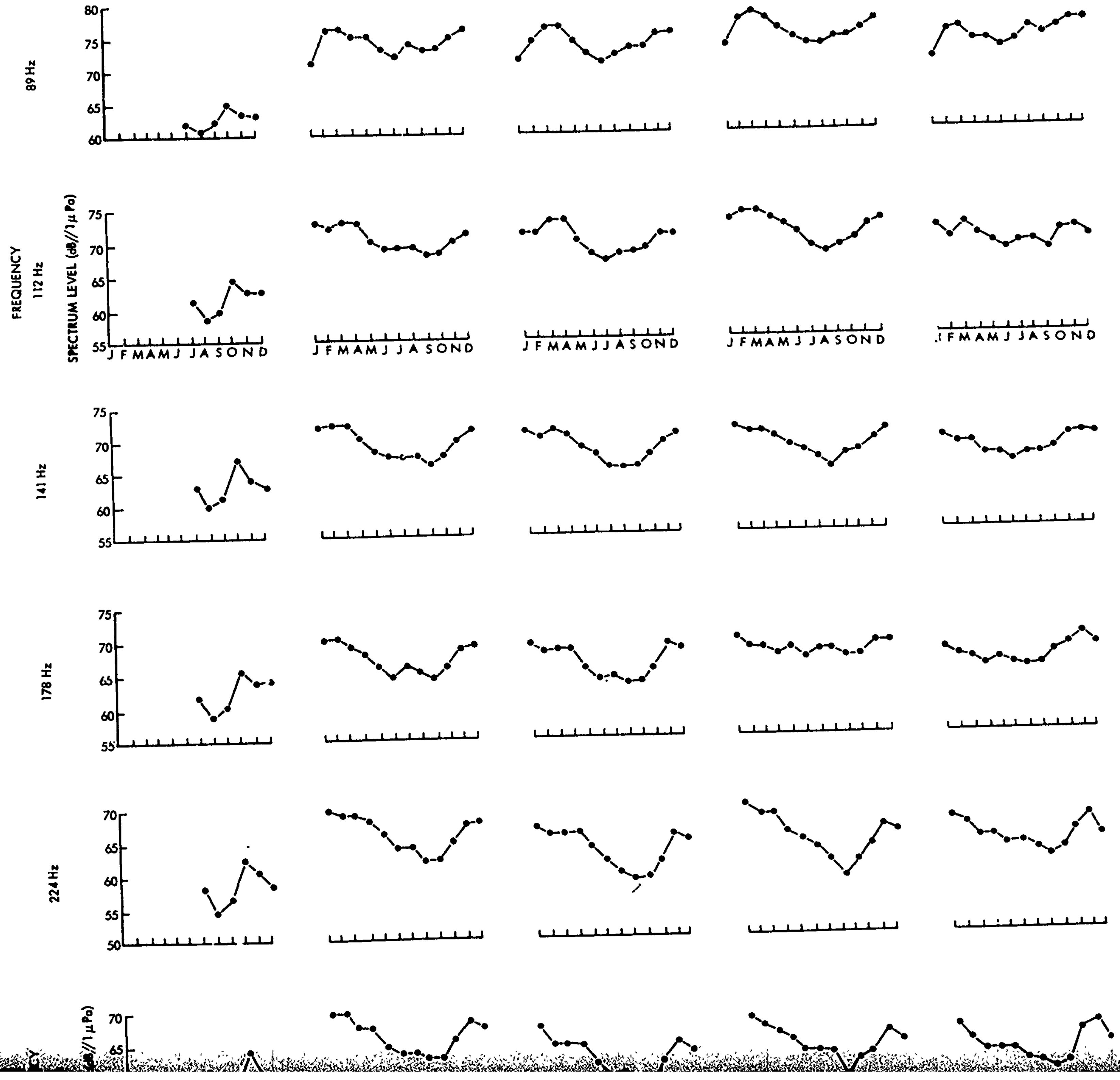
Figure 6. Monthly and Yearly Median Values of Ambient Noise Showing Upper and Lower Quartile Values for 5 Hydrophone Depths

4



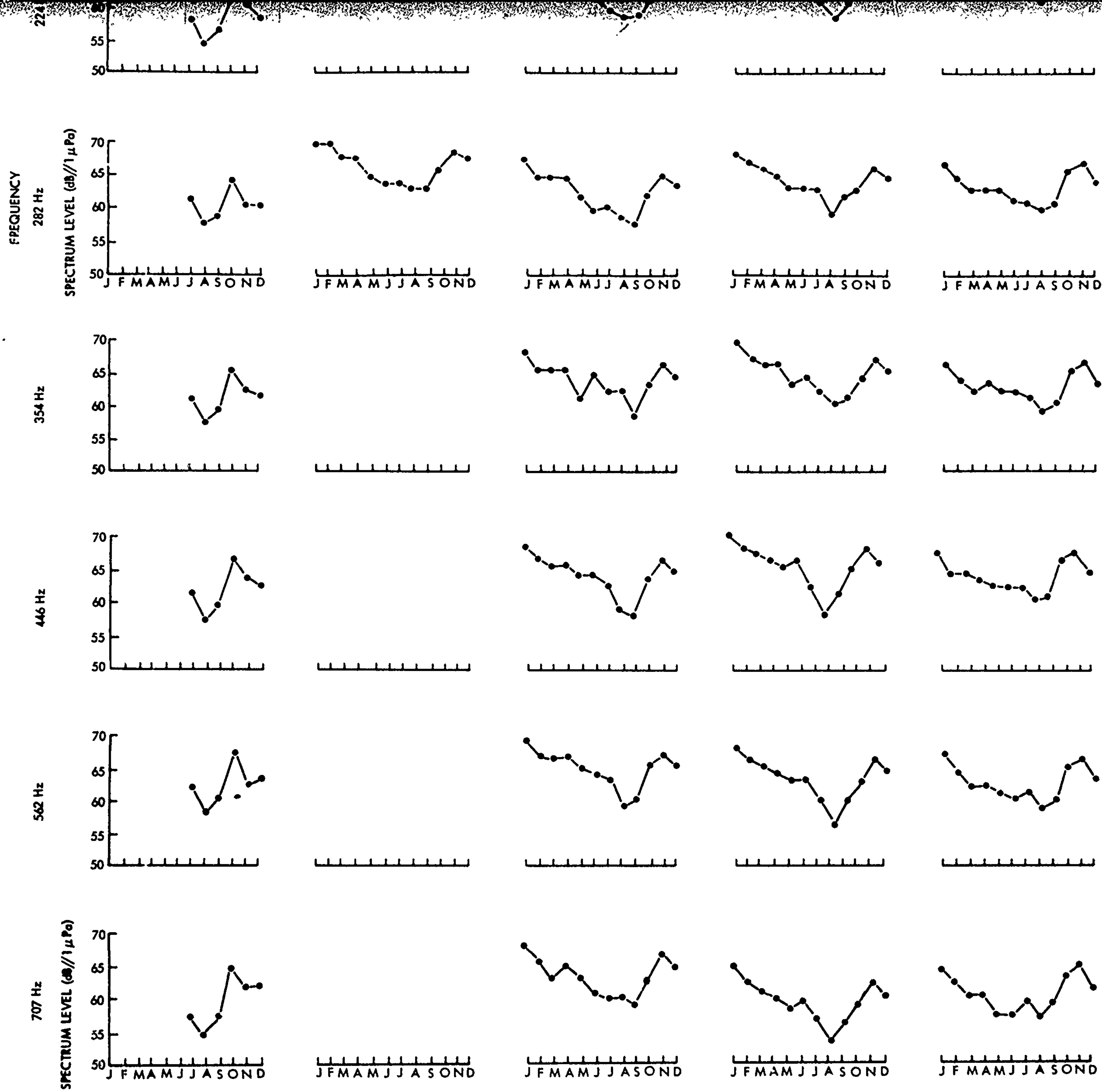
HYDROPHONE DEPTH (fm)
30
400
1100
2400
2500
FREQUENCY
11 Hz
14 Hz
17 Hz
22 Hz
28 Hz
SPECTRUM LEVEL (dB//1 μ Pa)
90
85
80
75
70
J F M A M J J A S O N D


28 Hz
35 Hz
FREQUENCY
44 Hz
56 Hz
70 Hz
89 Hz
SPECTRUM LEVEL (dB//1μ Pa)
J F M A M J J A S O N D



89 Hz
FREQUENCY
112 Hz
SPECTRUM LEVEL (dB//1 μPa)
141 Hz
178 Hz
224 Hz
J F M A M J J A S O N D
80
75
70
65
60
55
50

4



224
FREQUENCY
282 Hz
354 Hz
446 Hz
562 Hz
707 Hz
SPECTRUM LEVEL (dB//1 μPa)
70
65
60
55
50
J F M A M J J A S O N D

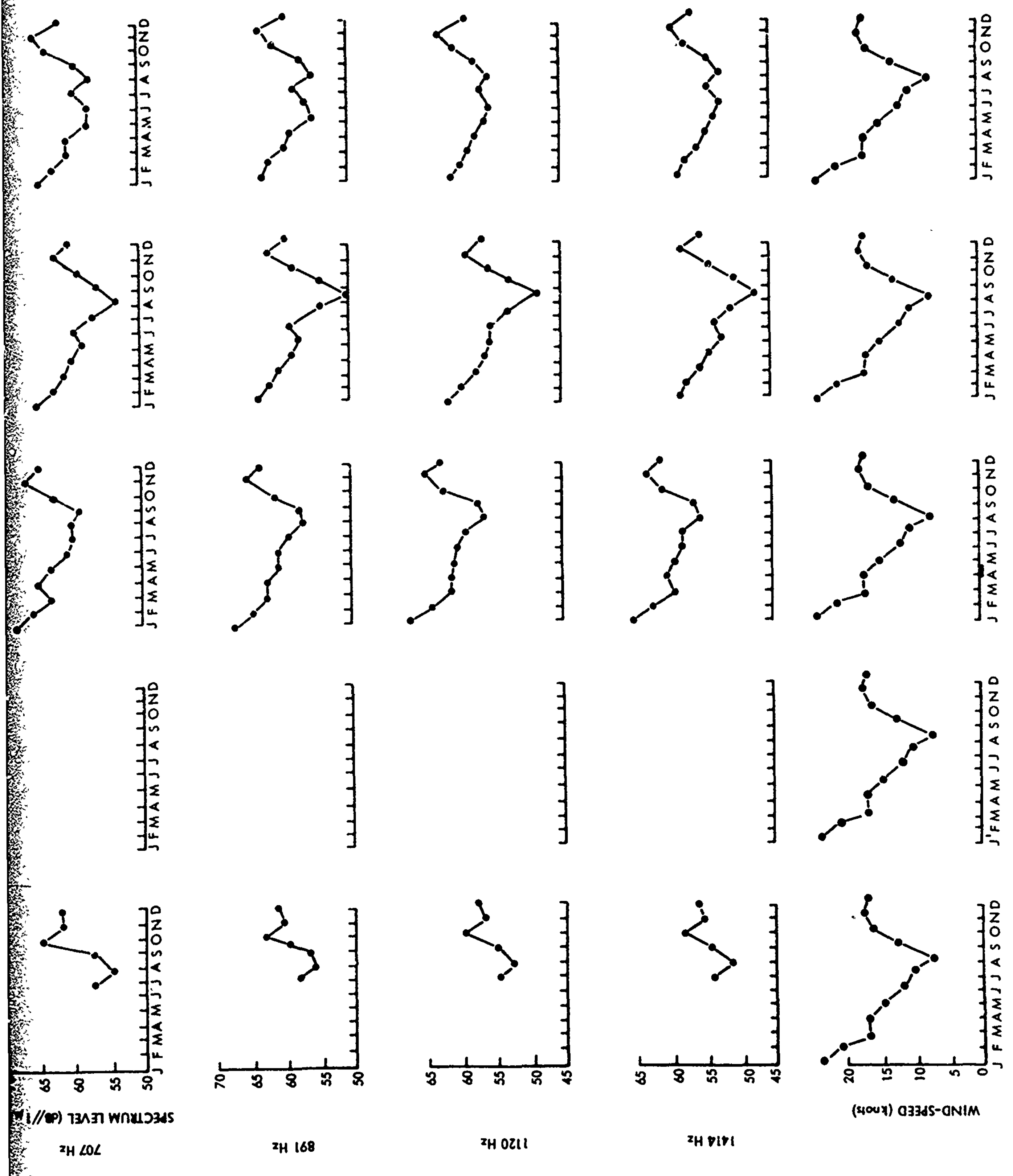


Figure 7. Monthly Logit Band Median Values of Ambient Noise for 22 Frequencies and 5 Hydrophone Depths Showing Monthly Median Wind Speed Values

5

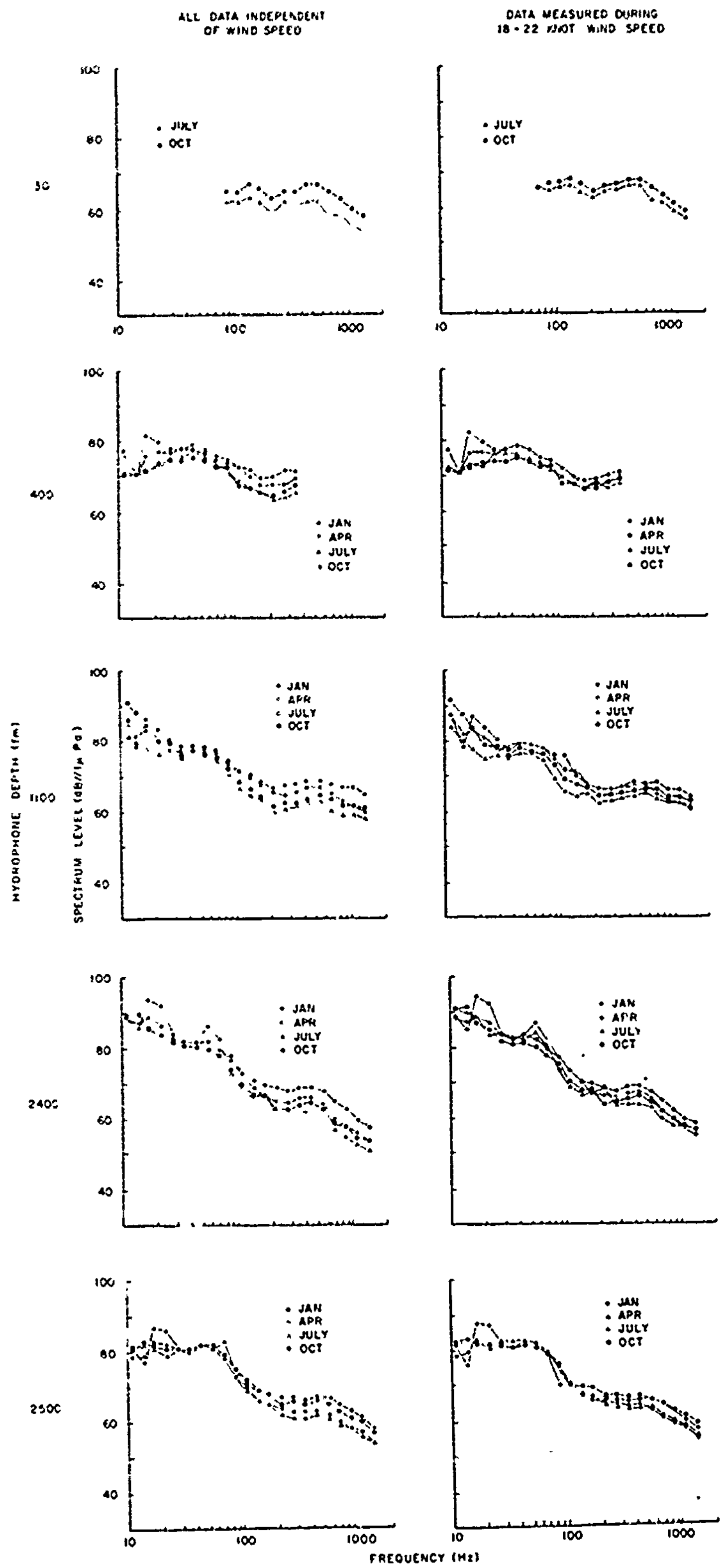


Figure 8. Comparison of Monthly Median Values for Four Seasons at 5 Hydrophone Depths, Depth as Parameter

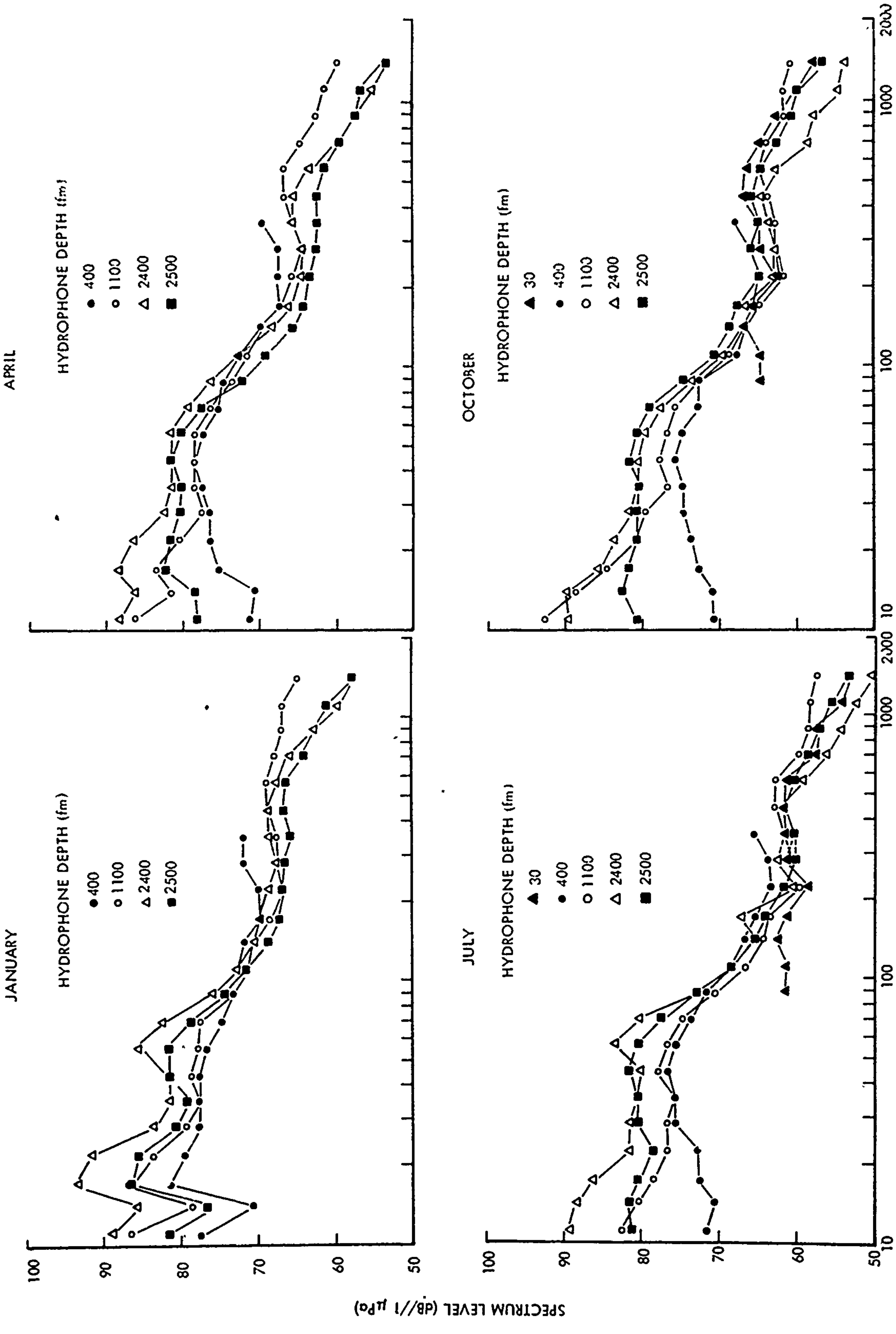


Figure 9. Comparison of Monthly Median Values for Four Seasons at 5 Hydrophone Depths

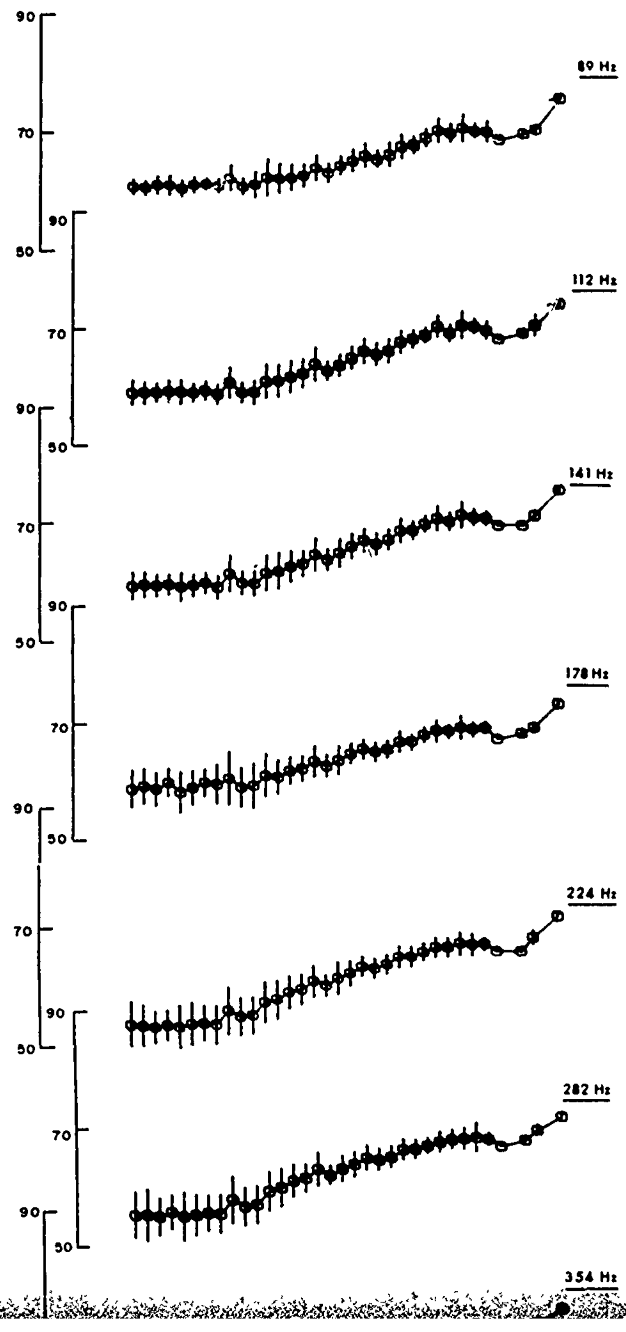
IV. MEAN AMBIENT NOISE LEVEL AND STANDARD DEVIATION VALUES

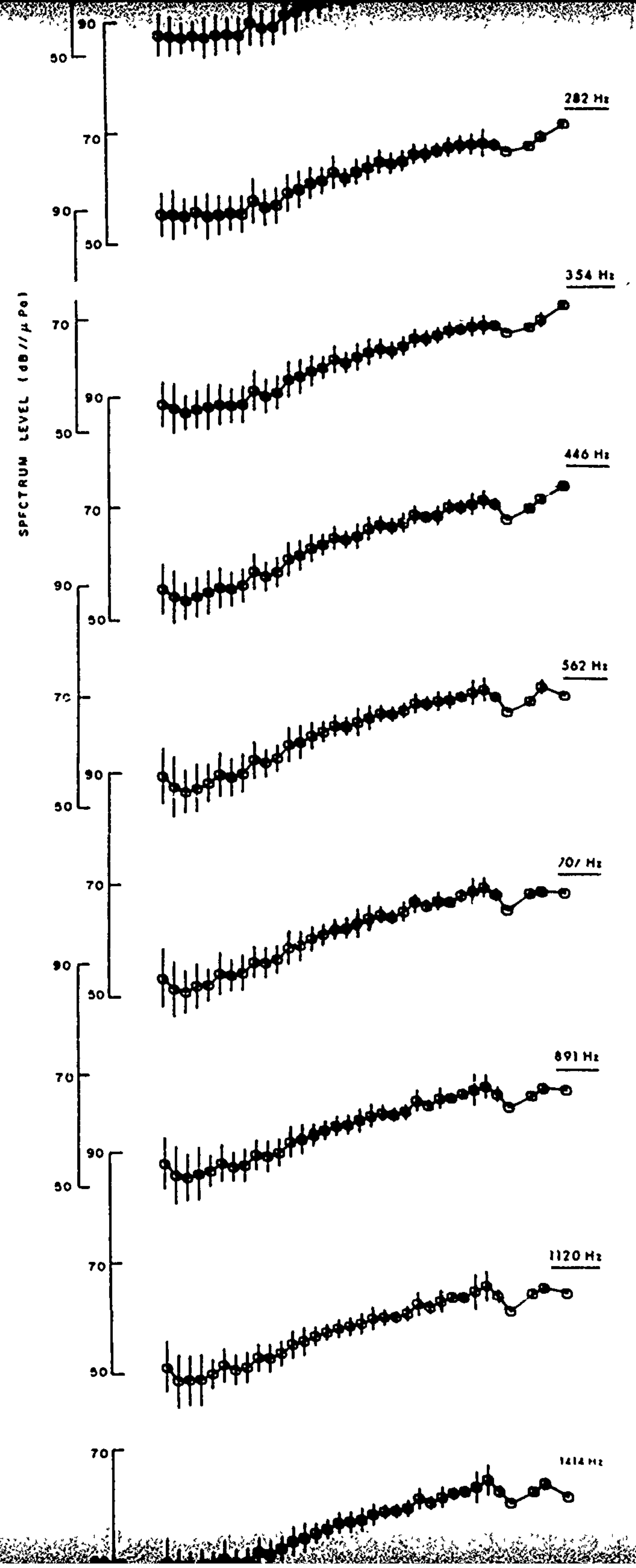
The mean value of ambient noise level and the standard deviation (denoted by the vertical lines) for the entire year of data were computed for each logit band as a function of 1 knot increments for wind speeds ranging from 0 to 50 knots. The results for each hydrophone depth (i.e., 30, 400, 1100, 2400, and 2500 fm or 55, 730, 2000, 4400, 4500 m) are shown in figures 10 through 14. As would be expected by reviewing figure 4 strong wind dependence is prevalent in the upper bands (i.e., between 141 and 1414 Hz), with the dependence increasing as frequency increases.

The noise in the 17 to 112 Hz bands is dominated by noise sources other than wind except at very high wind speeds. The noise in the 11 and 14 Hz bands shows an increase in level with increasing wind speed only when wind speed exceeds 25 knots. A greater wind dependence is observed for the 30 fm (55 m) hydrophone than for the deeper hydrophones, especially at frequencies below 141 Hz. The increased wind dependence is probably the result of the 30 fm (55 m) hydrophone being located such that propagation from distant sources was poor. That is, as local wind speed increases, the effects of local sources become more prominant and there is greater wind dependence. Such dependence decreases with increased hydrophone depth.

The standard deviation is observed to be relatively constant and independent of wind speeds for frequencies below 141 Hz. Above that frequency the standard deviation is greatest at low wind speeds, increases with increasing frequency, and decreases with increasing wind speed. The high variability at the greatest wind speeds probably results from the small sample size for those speeds.

HYDROPHONE DEPTH 30 (fm)





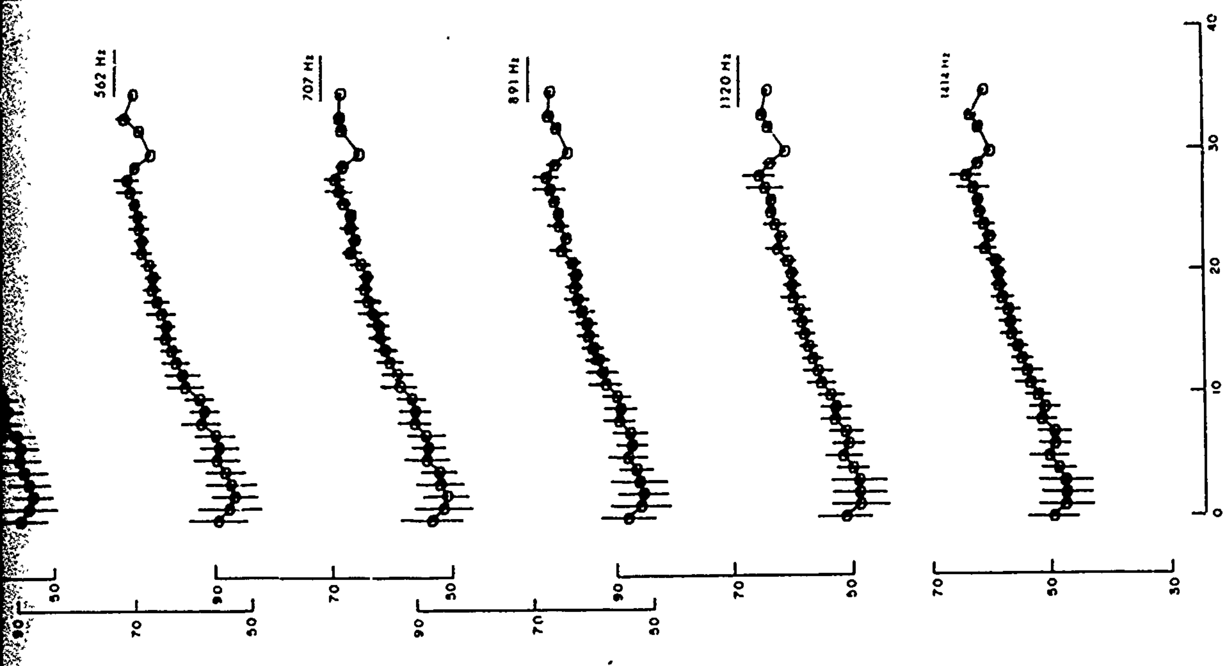
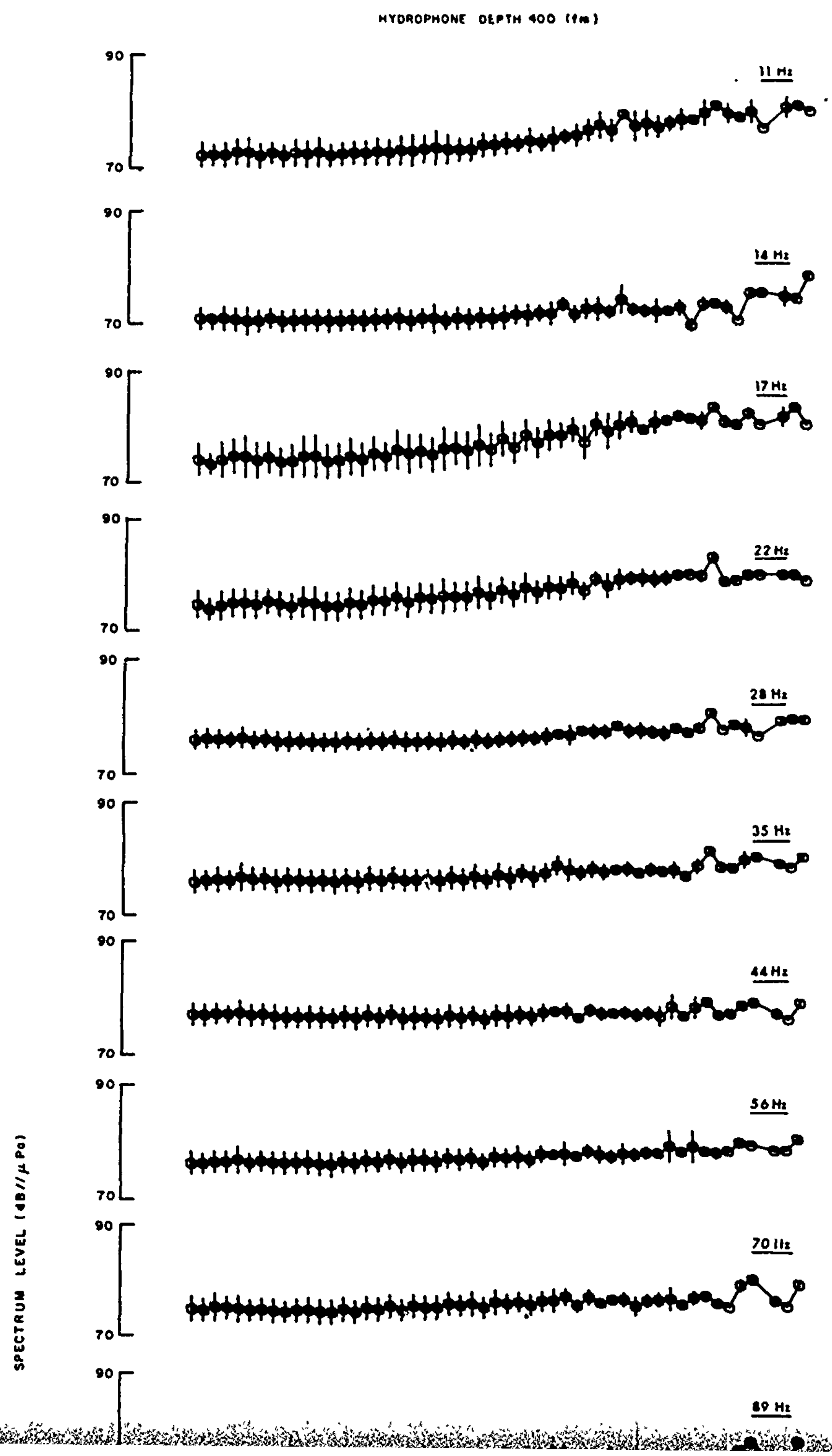
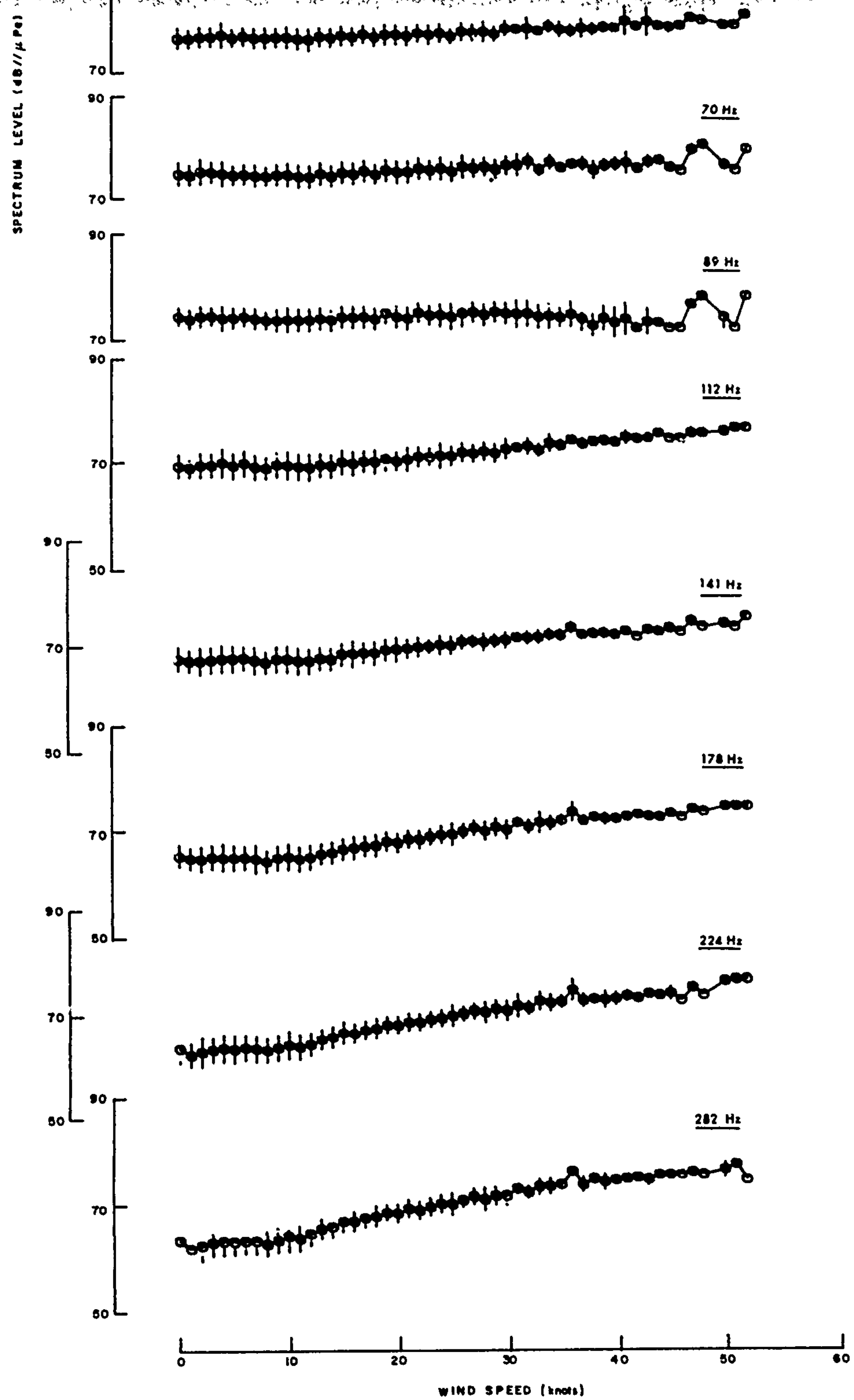


Figure 10. Ambient Noise Level Versus 1 knot Wind Speed Increments, Hydrophone Depth 30 fm (55 m)

2


HYDROPHONE DEPTH 400 (fm)
SPECTRUM LEVEL (dB//μPa)
90
70
11 Hz
14 Hz
17 Hz
22 Hz
28 Hz
35 Hz
44 Hz
56 Hz
70 Hz
89 Hz


SPECTRUM LEVEL (dB//μPa)
70 Hz
89 Hz
112 Hz
141 Hz
178 Hz
224 Hz
282 Hz
90
70
50
0
10
20
30
40
50
60
WIND SPEED (knots)

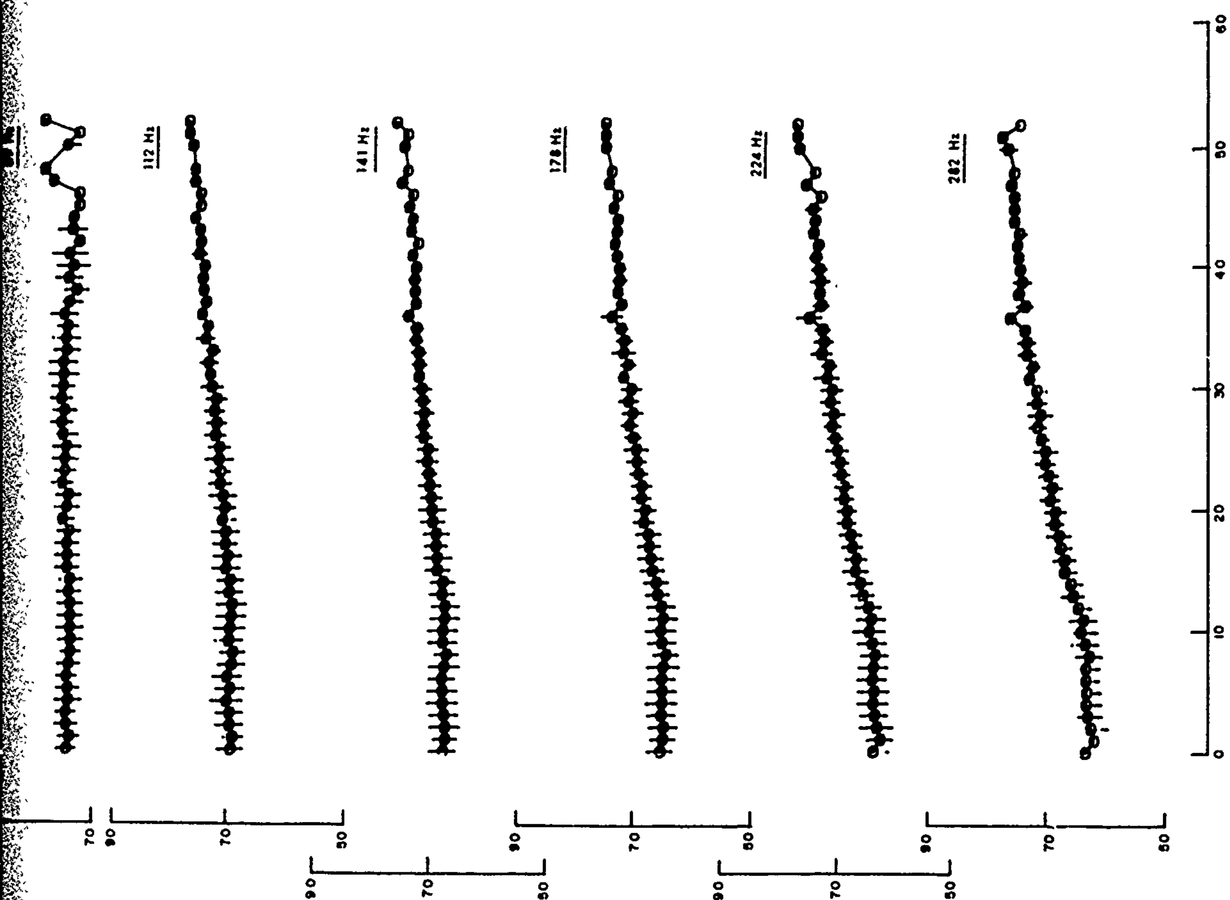
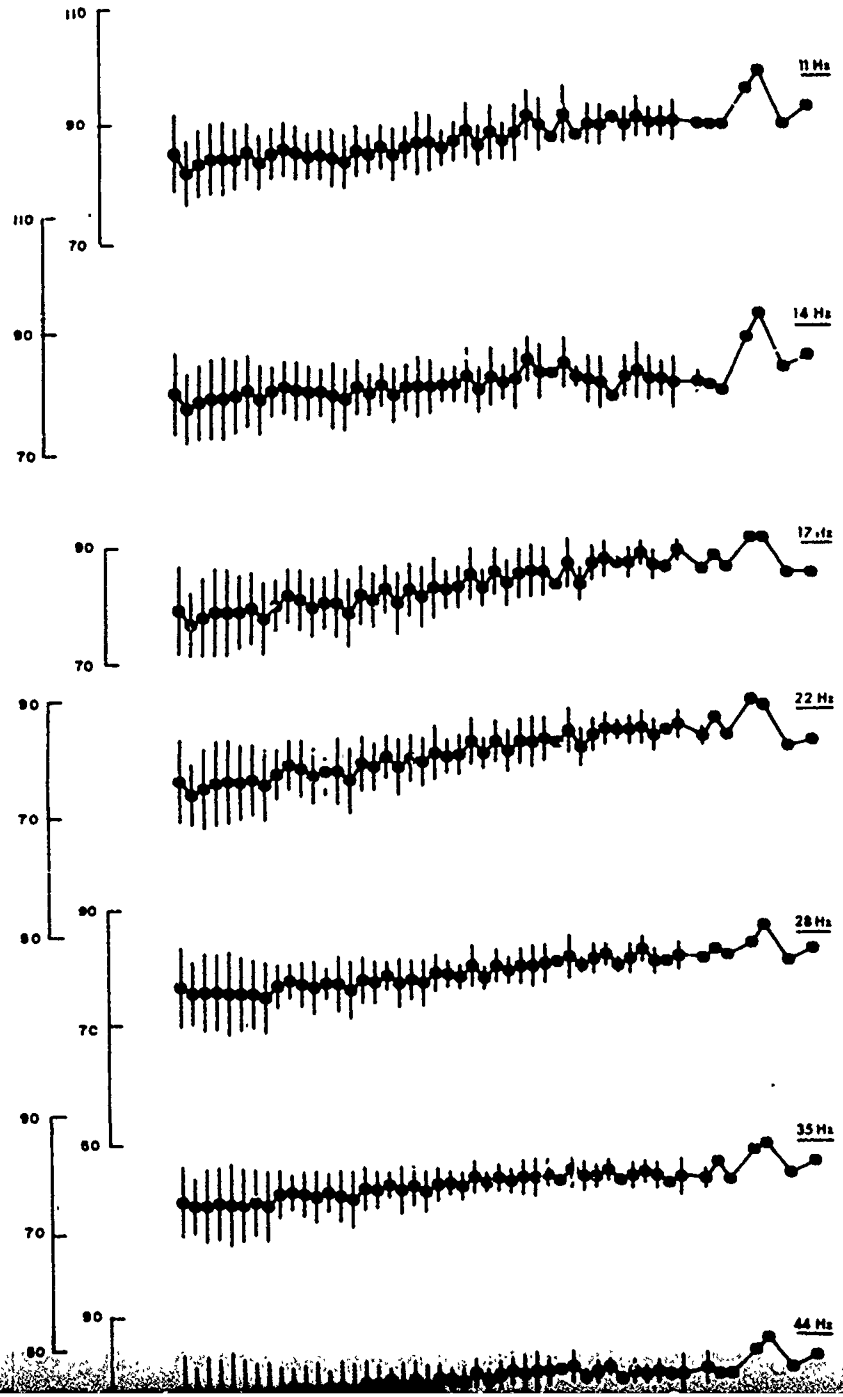
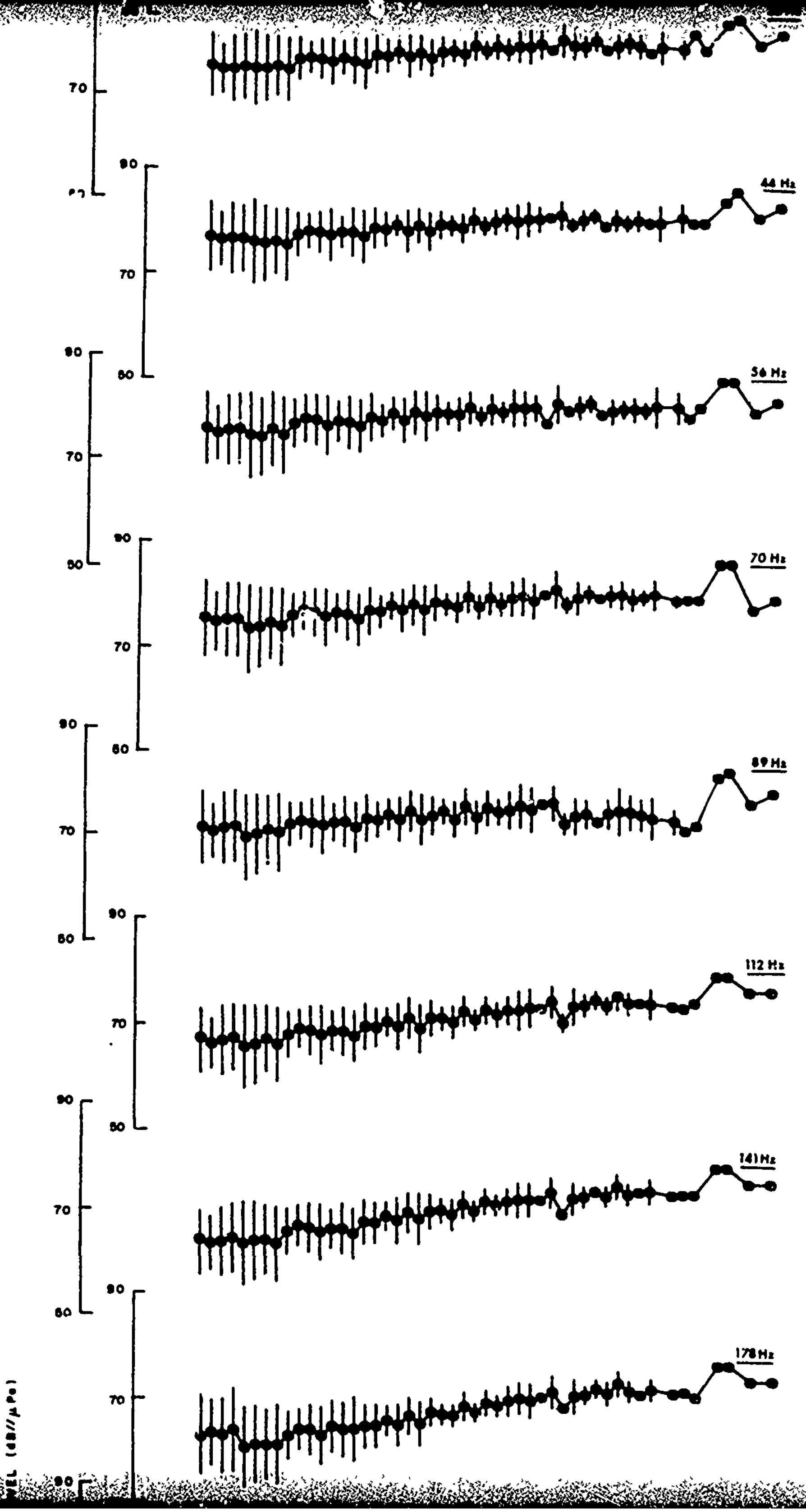


Figure 11. Ambient Noise Level Versus 1 knot Wind Speed Increments, Hydrophone Depth 400 fm (730 m)

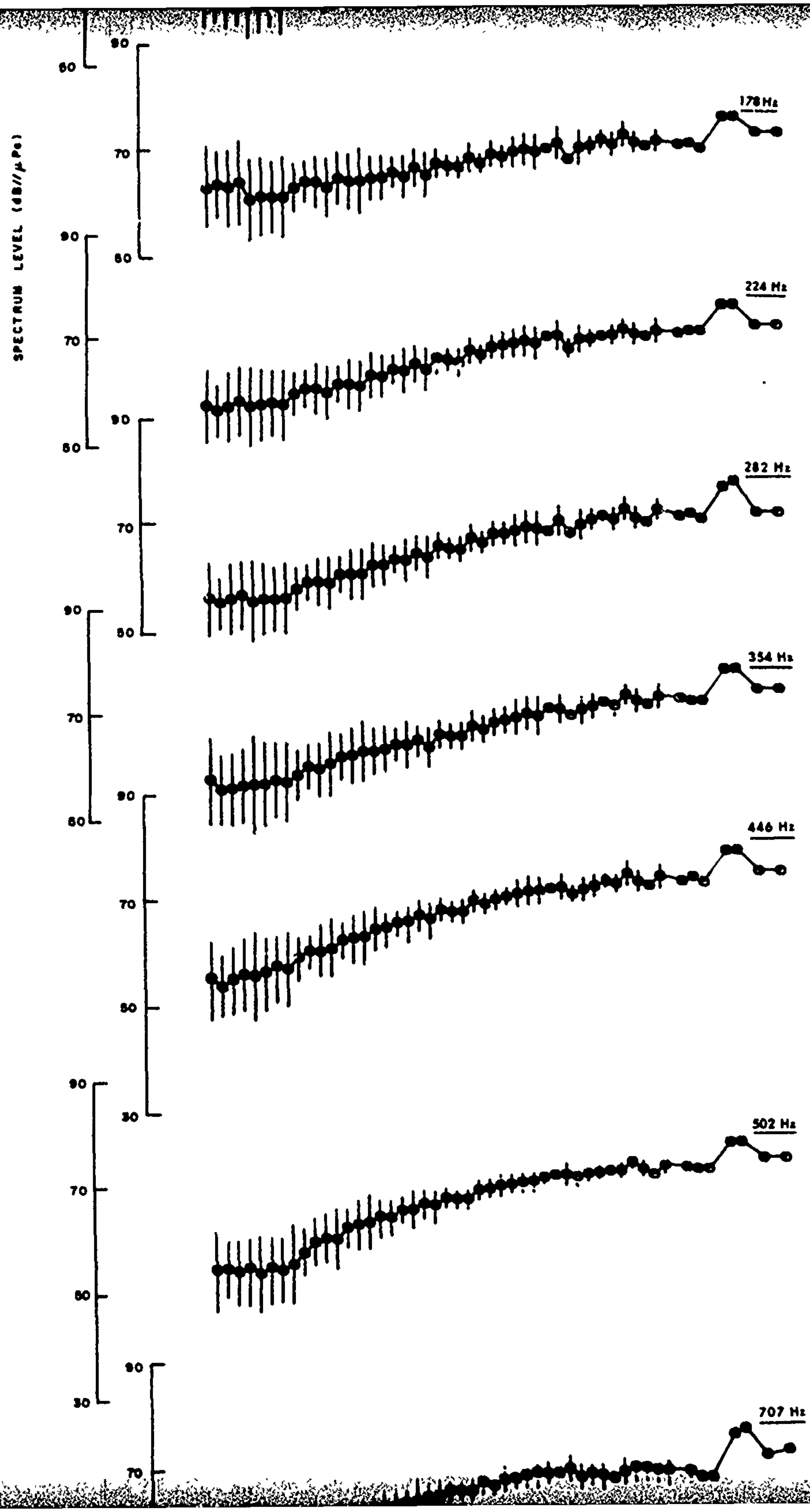
HYDROPHONE DEPTH 1100 (fm)





44 Hz
56 Hz
70 Hz
89 Hz
112 Hz
141 Hz
178 Hz
90
70
60
(dB//μPa)

3


SPECTRUM LEVEL (dB//µPa)
178 Hz
224 Hz
282 Hz
354 Hz
446 Hz
502 Hz
707 Hz
90
70
50
30

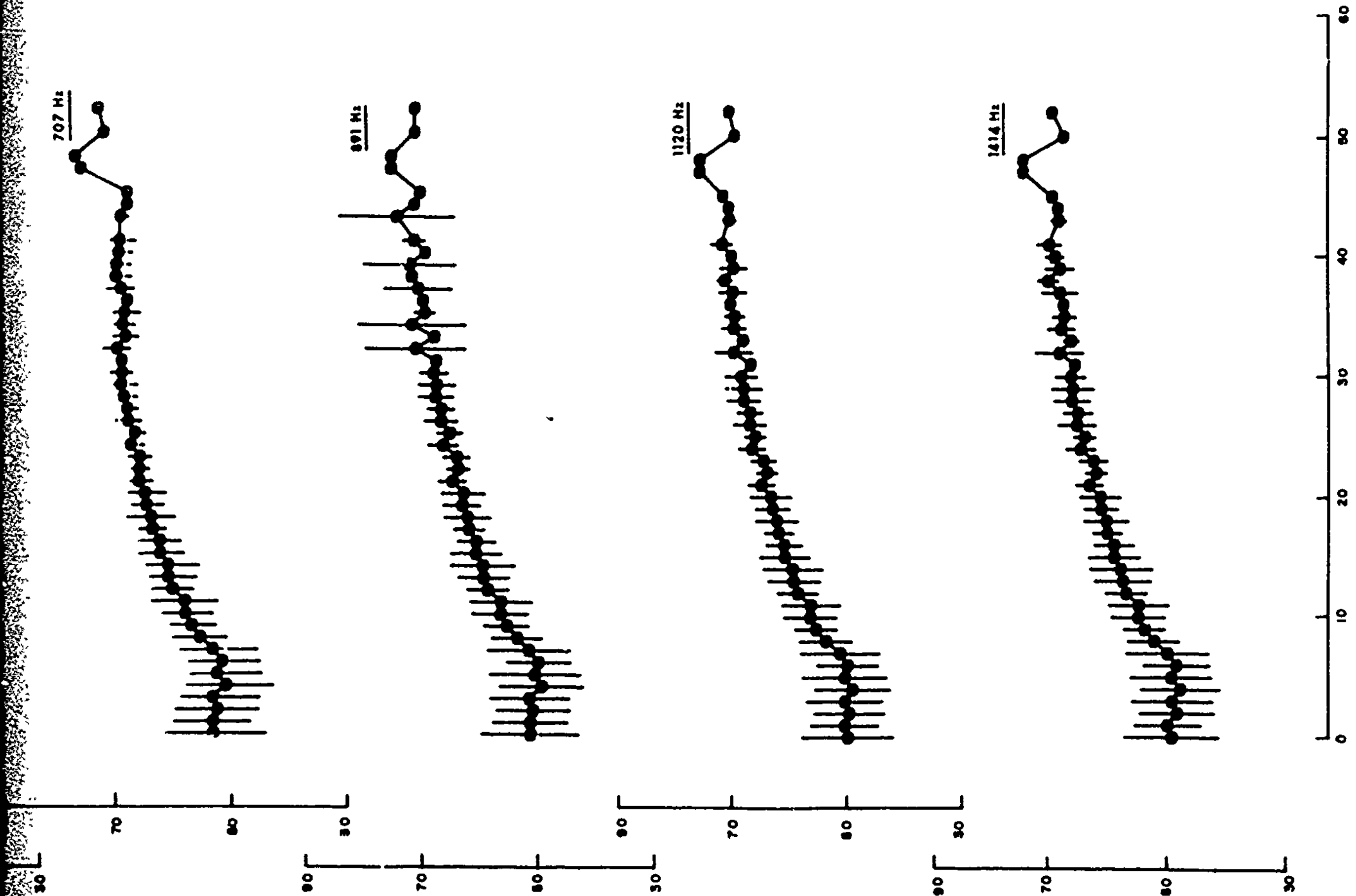
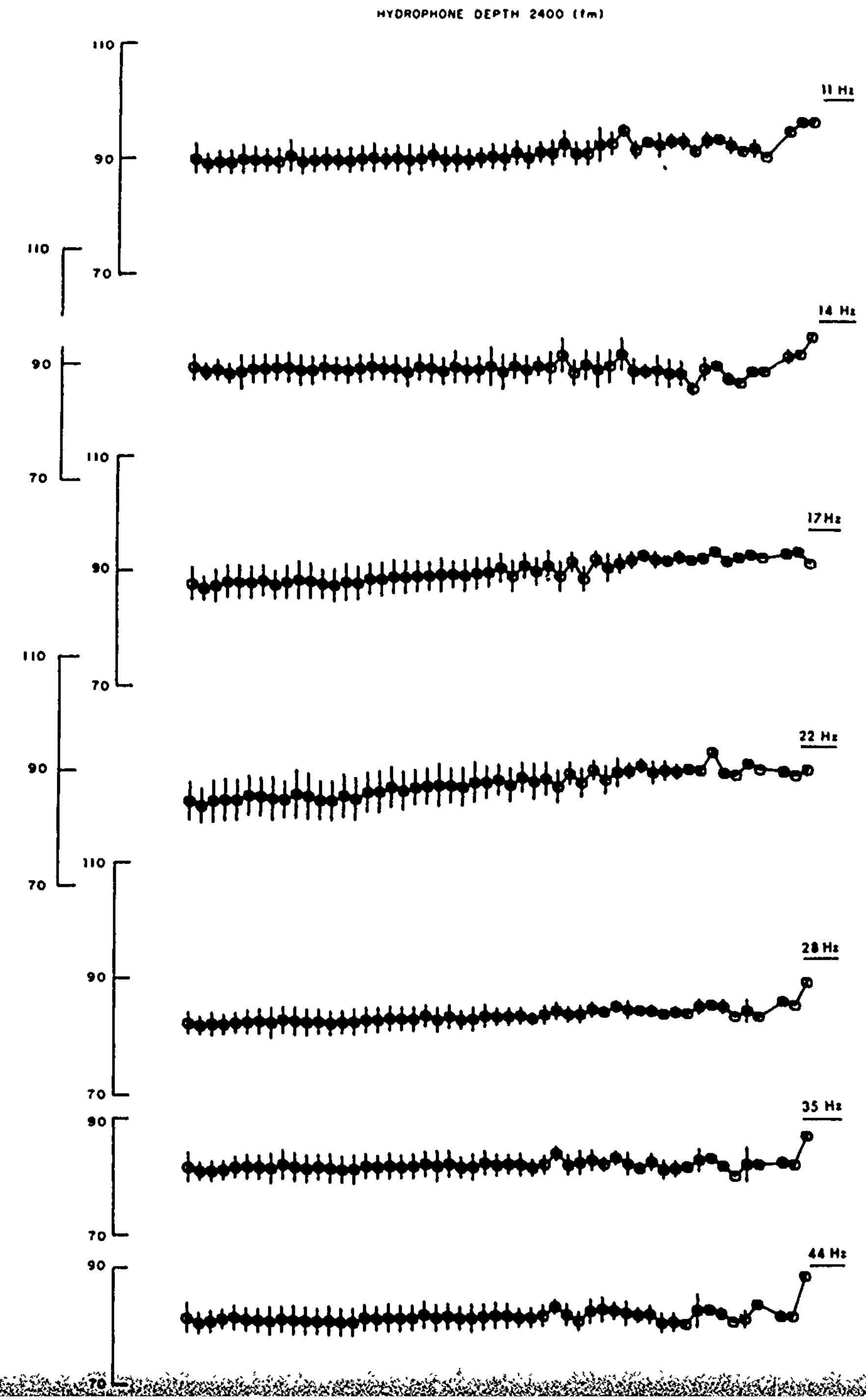
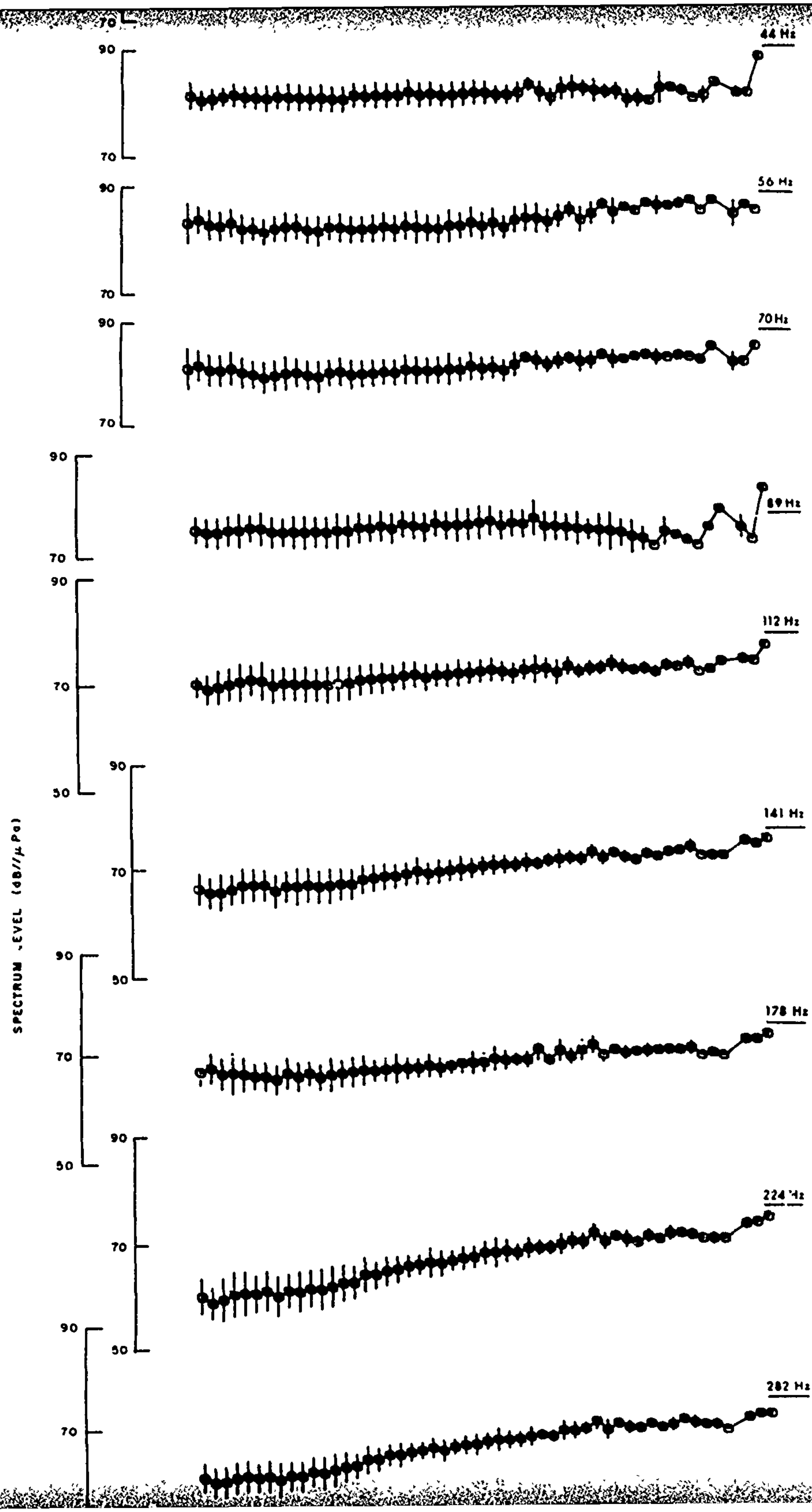


Figure 12. Ambient Noise Level Versus 1 knot Wind Speed Increments, Hydrophone Depth 1100 fm (2000 m)

4

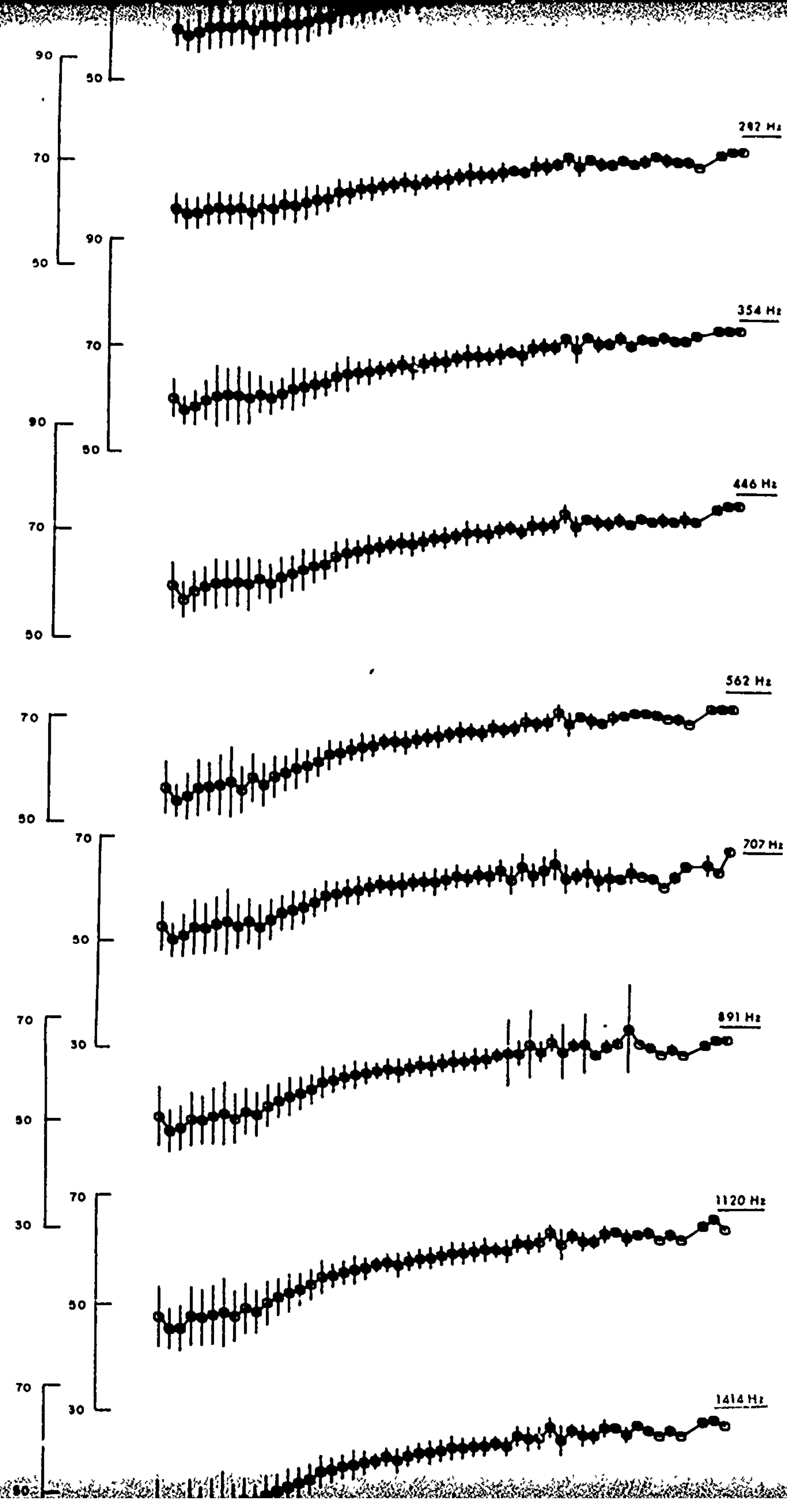


HYDROPHONE DEPTH 2400 (fm)
110
90
70
11 Hz
14 Hz
17 Hz
22 Hz
28 Hz
35 Hz
44 Hz


44 Hz
56 Hz
70 Hz
89 Hz
112 Hz
141 Hz
178 Hz
224 Hz
282 Hz
90
70
50
SPECTRUM LEVEL (dB//μPa)

2

3



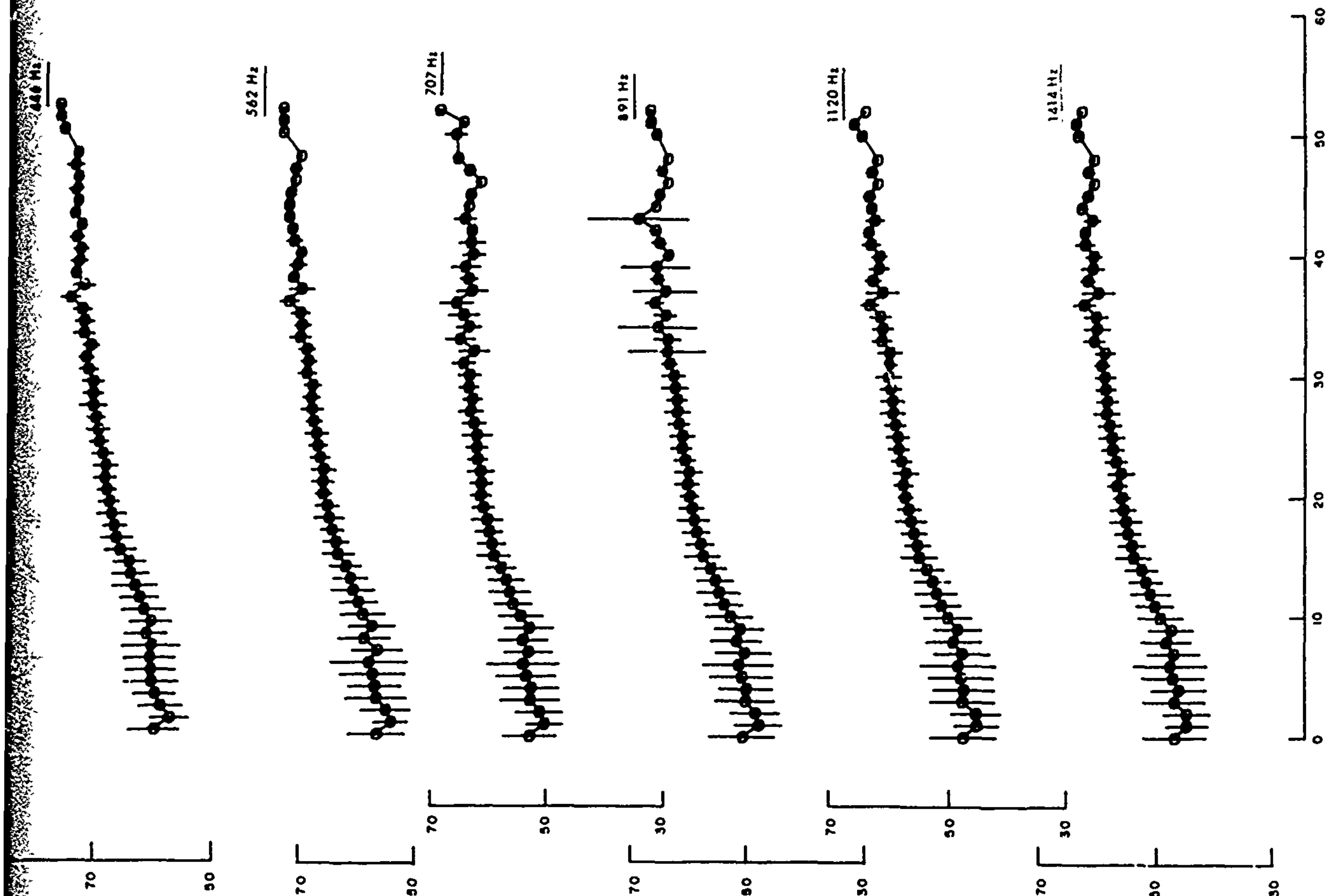
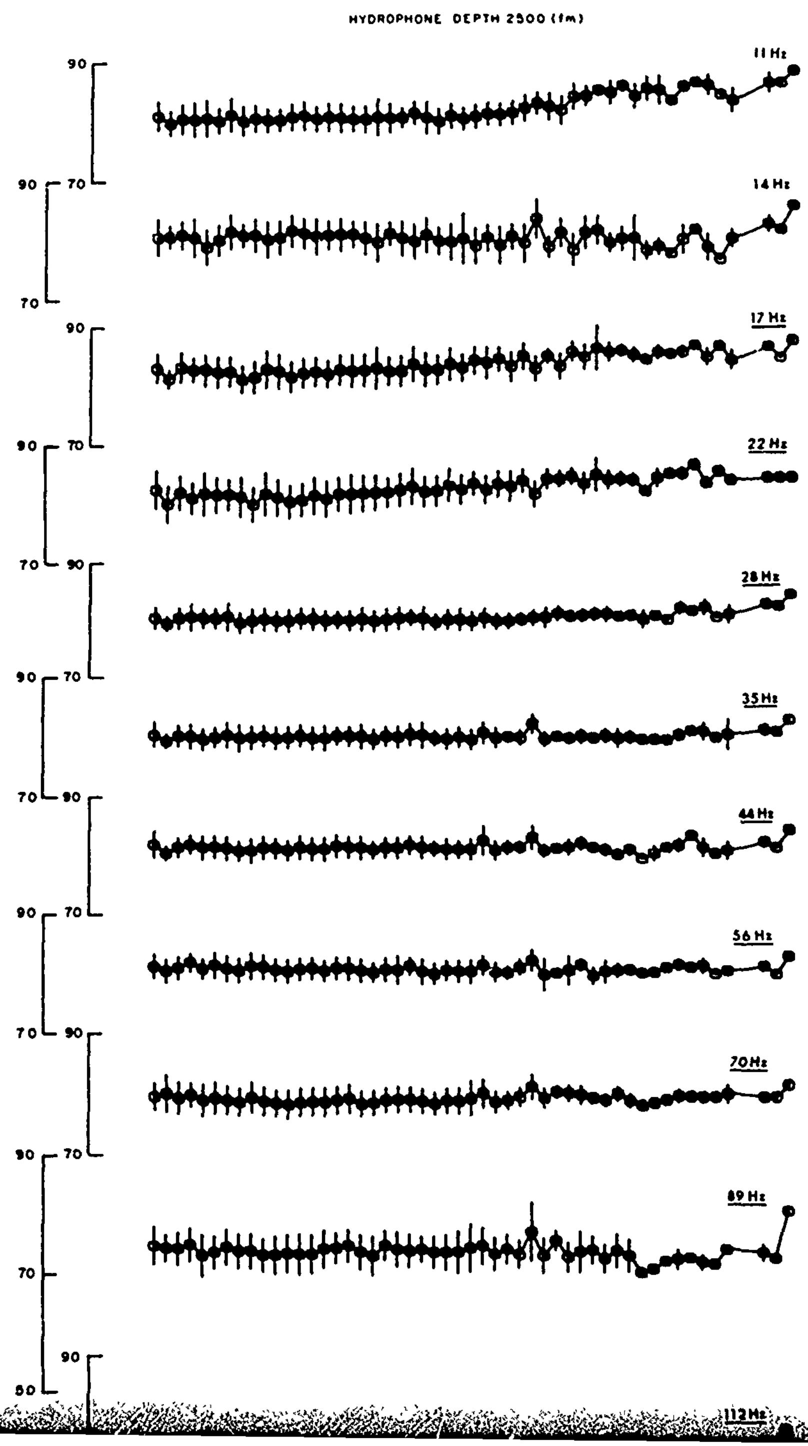
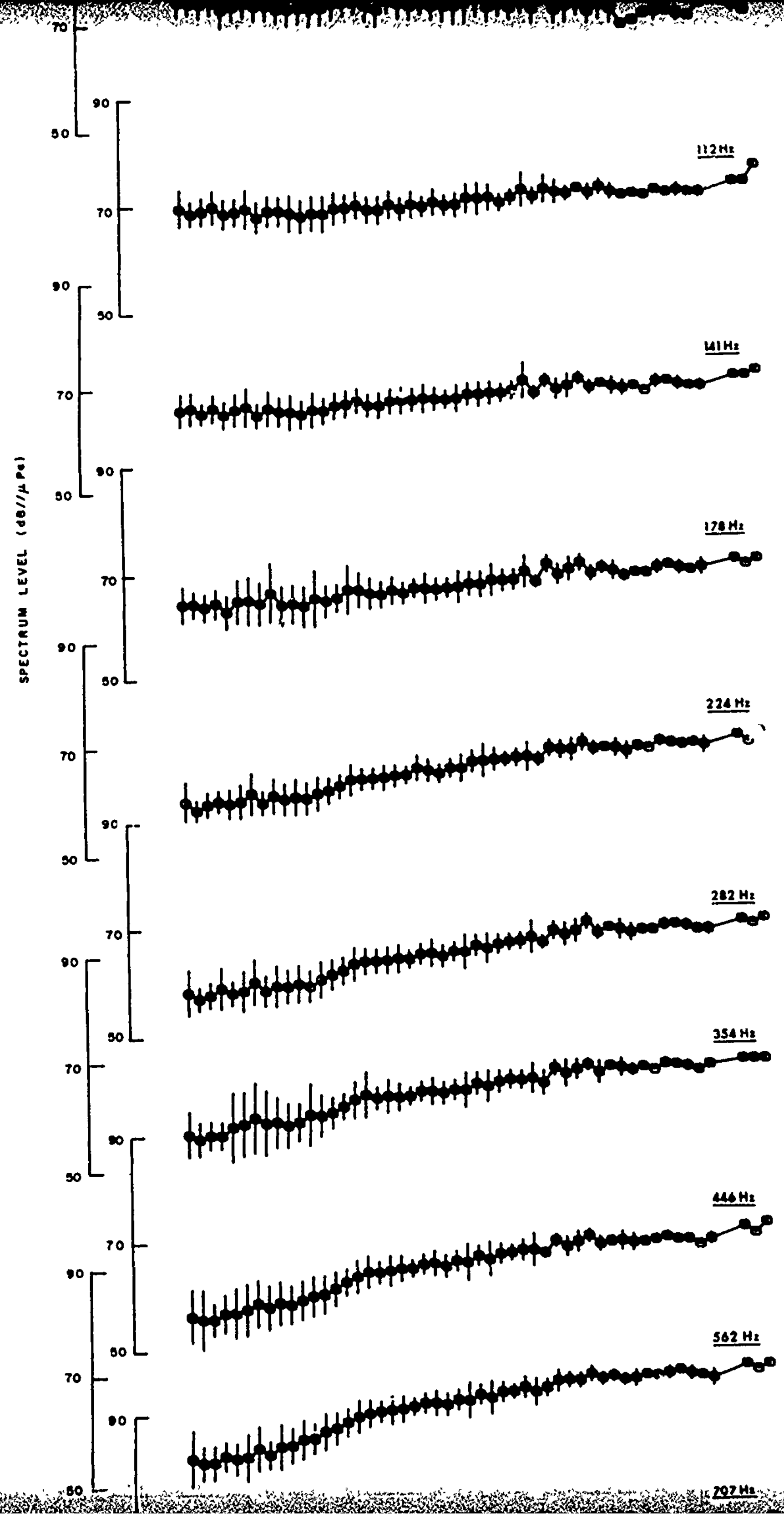


Figure 13. Ambient Noise Level Versus 1 knot Wind Speed Increments, Hydrophone Depth 2400 fm (4400 m)



HYDROPHONE DEPTH 2500 (fm)
11 Hz
14 Hz
17 Hz
22 Hz
28 Hz
35 Hz
44 Hz
56 Hz
70 Hz
89 Hz
112 Hz
90
70
50



SPECTRUM LEVEL (dB//µPa)
112 Hz
141 Hz
178 Hz
224 Hz
282 Hz
354 Hz
446 Hz
562 Hz
707 Hz

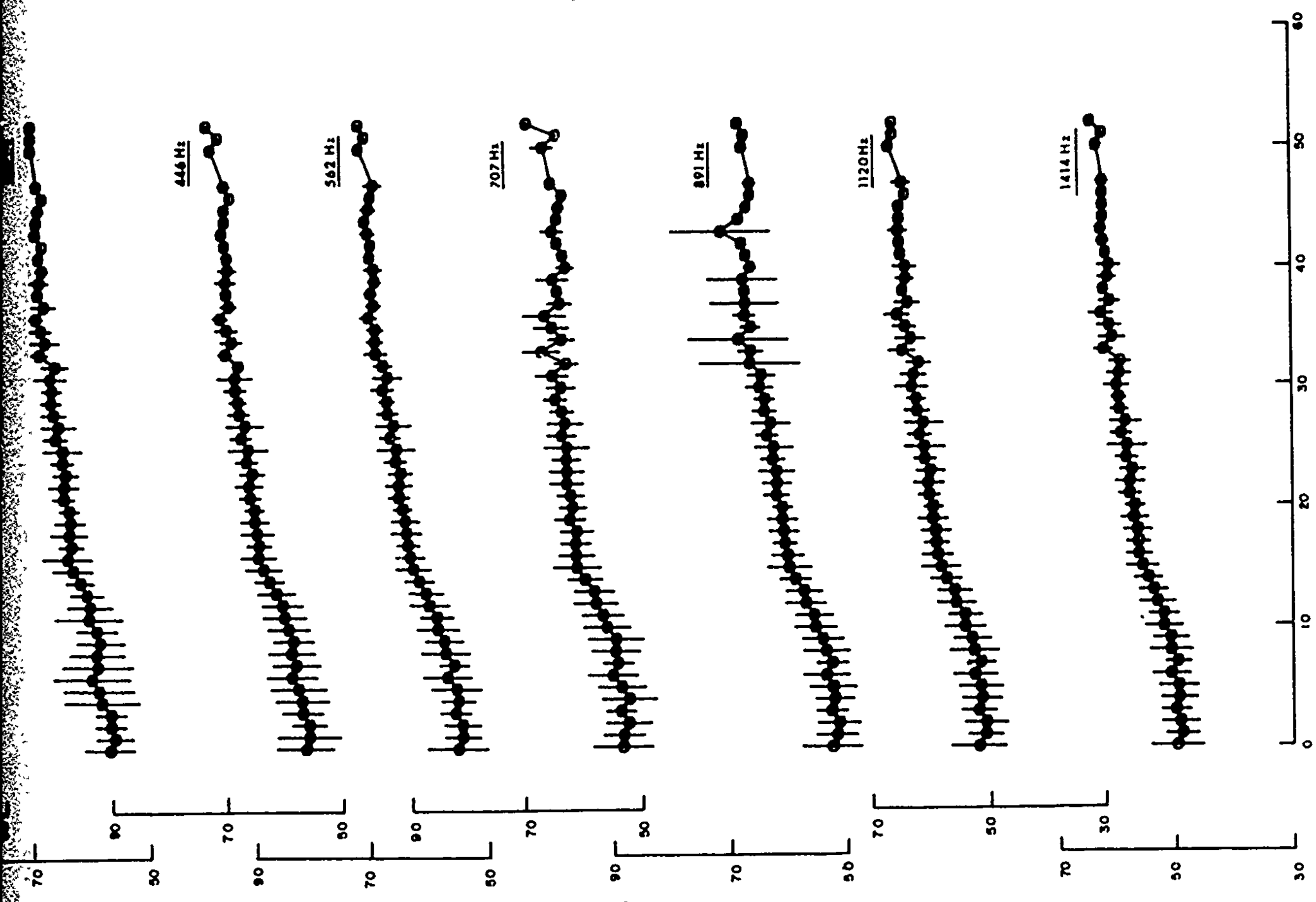
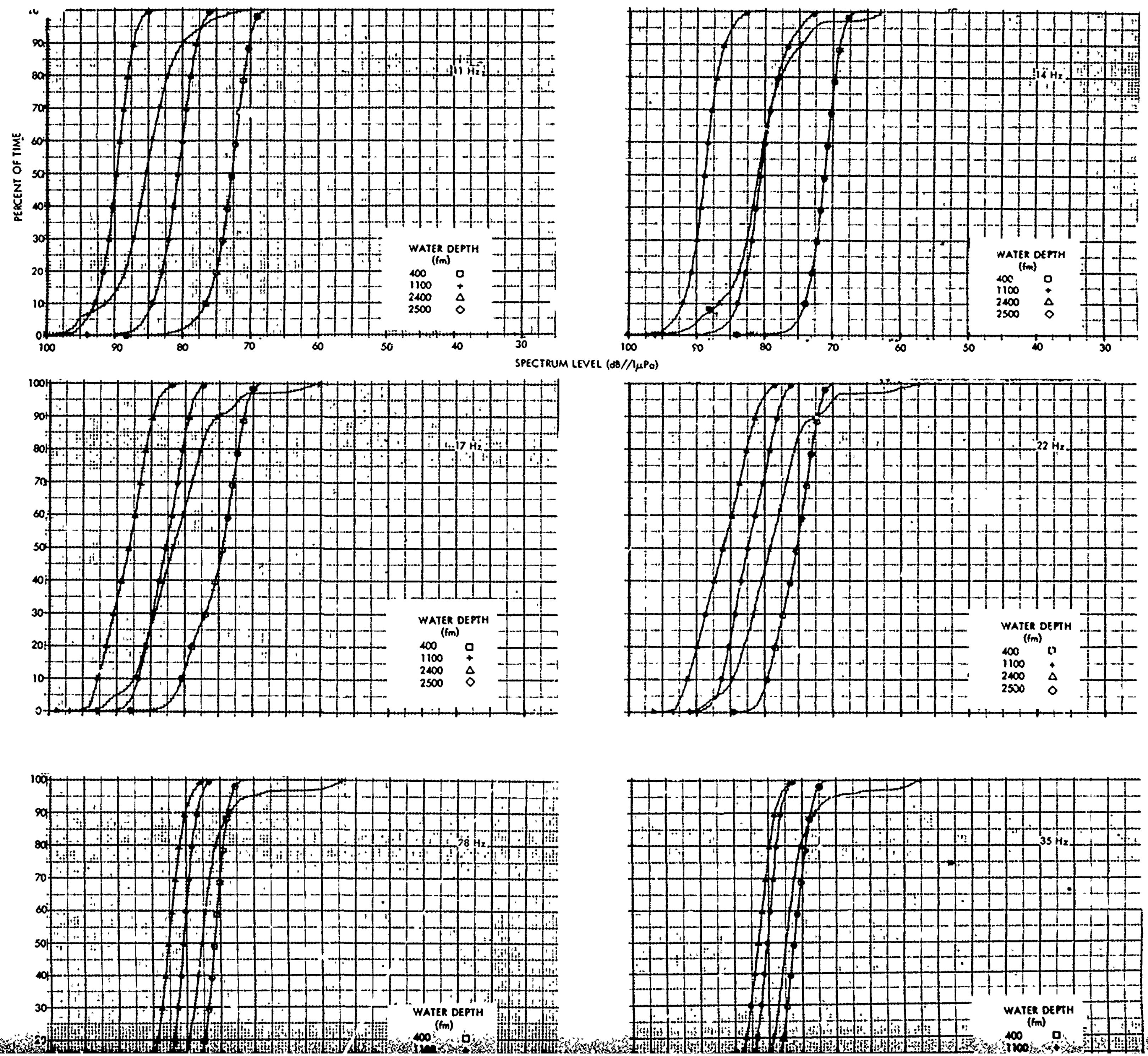
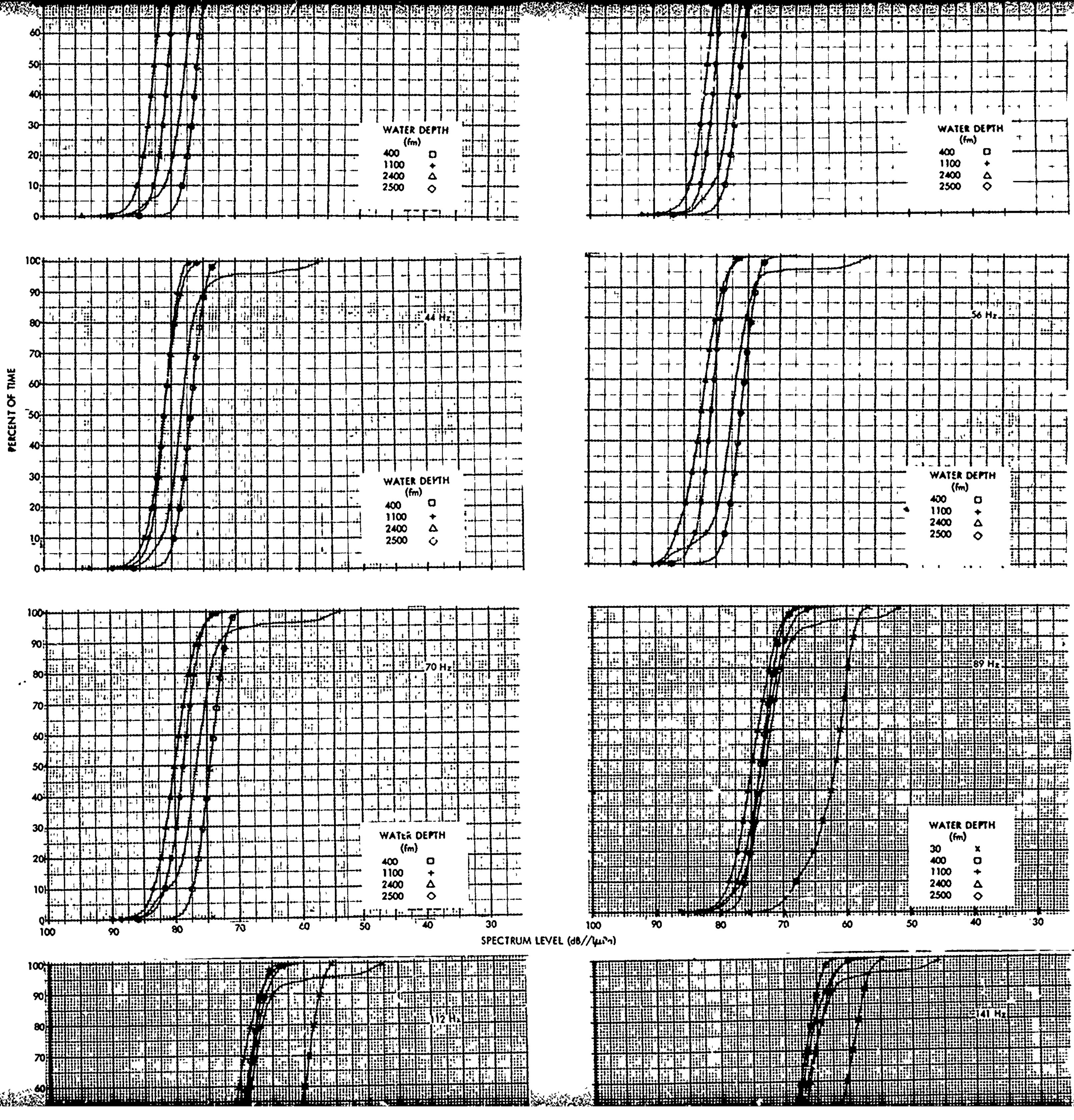


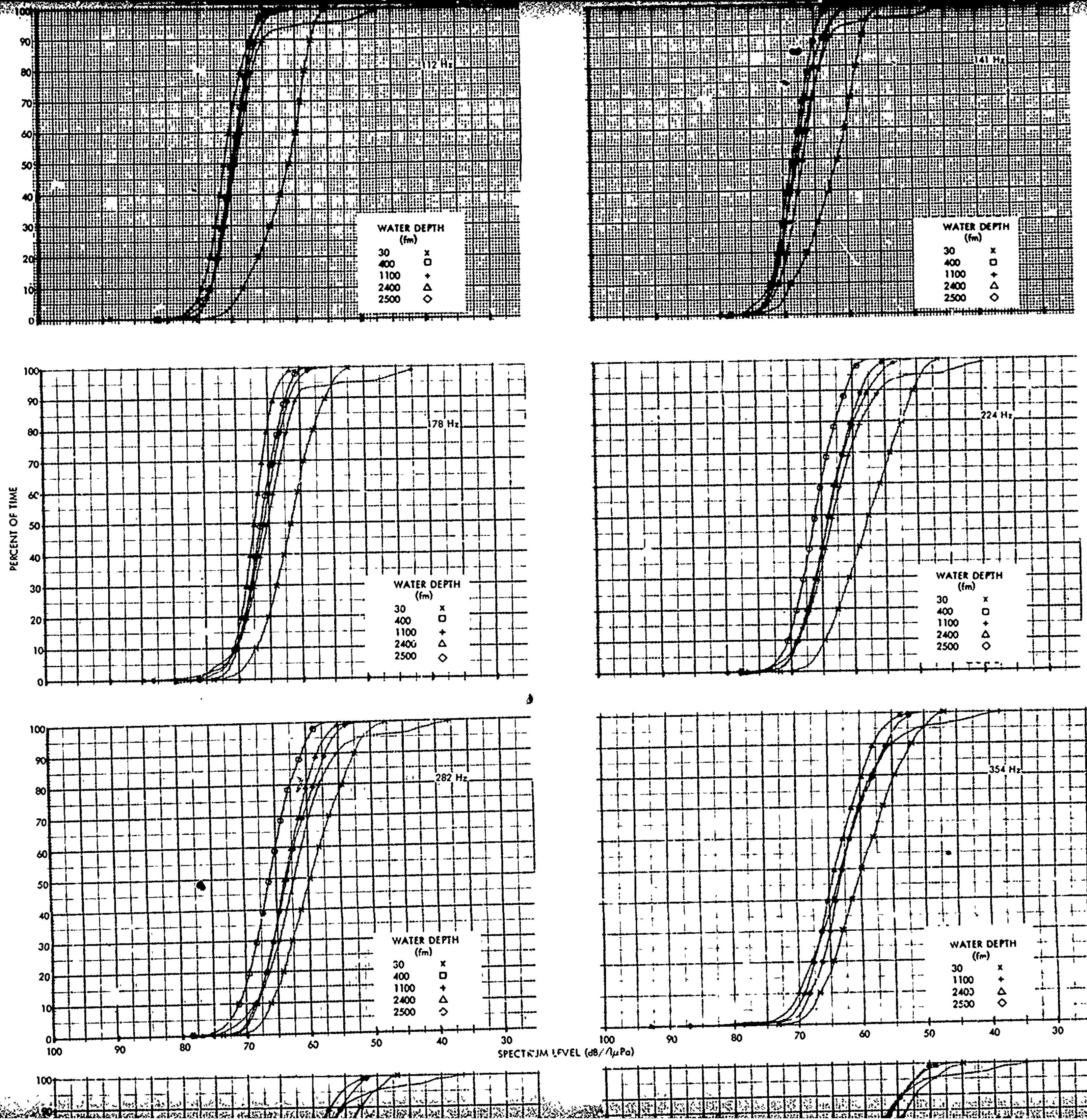
Figure 14. Ambient Noise Level Versus 1 knot Wind Speed Increments, Hydrophone Depth 2500 fm (4500 m)

V. CUMULATIVE DISTRIBUTION OF AMBIENT NOISE LEVELS

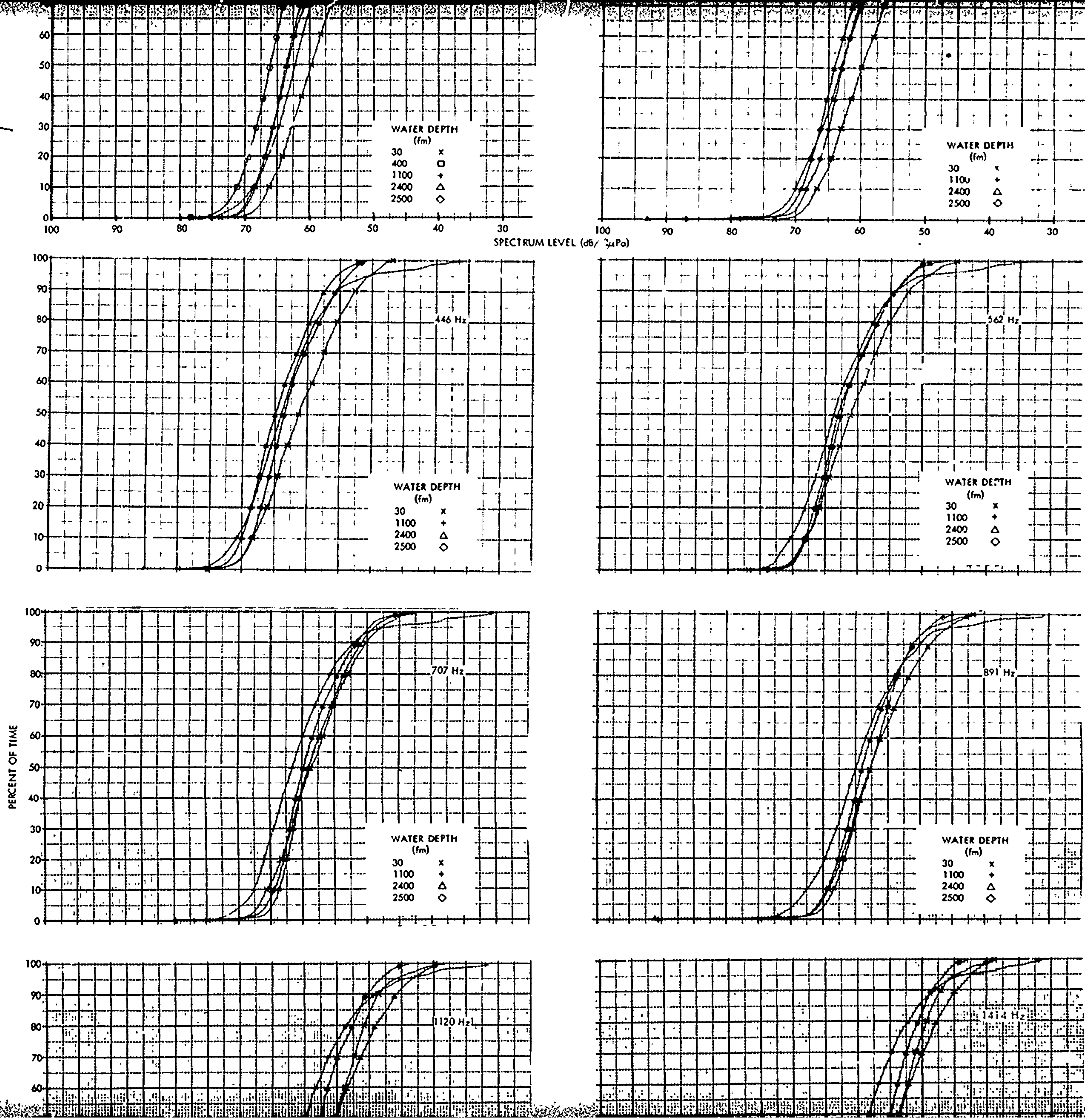
Cumulative distributions of the ambient noise levels for the entire year of data were computed in 1 dB increments for each of the logit frequency bands ranging from 11 to 1414 Hz and for each hydrophone depth; the results are shown in figure 15. The maximum difference in level as a function of hydrophone depth is approximately 17 dB at 11 Hz. This difference decreases with increasing frequency up to 112 Hz where, with the exception of 30 fm (55 m) hydrophone, a minimum difference of 2 to 3 dB is observed between the other hydrophones. Above 112 Hz the difference in level remains relatively constant up to 1414 Hz, varying between 4 and 7 dB. The relative degree of wind dependence as a function of frequency is indicated by differences in the slopes of the distributions. Little wind dependence is observed between 28 and 89 Hz where the slopes of the curves are more nearly vertical than are those below 22 Hz and above 112 Hz, where the slopes are less vertical (i.e., more wind dependent). Maximum wind dependence is observed at 1414 Hz.


11 Hz
14 Hz
17 Hz
22 Hz
28 Hz
35 Hz
PERCENT OF TIME
SPECTRUM LEVEL (dB//1μPa)
WATER DEPTH (fm)
400
1100
2400
2500


WATER DEPTH (fm)
400 □
1100 +
2400 △
2500 ◇
PERCENT OF TIME
44 Hz
56 Hz
70 Hz
69 Hz
WATER DEPTH (fm)
30 x
400 □
1100 +
2400 △
2500 ◇
SPECTRUM LEVEL (dB//μPa)
112 Hz
141 Hz


112 Hz
141 Hz
178 Hz
224 Hz
282 Hz
354 Hz
WATER DEPTH (fm)
30 x
400 □
1100 +
2400 △
2500 ◇
PERCENT OF TIME
SPECTRUM LEVEL (dB//μPa)

4


WATER DEPTH (fm)
30 x
400 □
1100 +
2400 △
2500 ◇
WATER DEPTH (fm)
30 x
1100 +
2400 △
2500 ◇
SPECTRUM LEVEL (dB/ 1μPa)
446 Hz
562 Hz
707 Hz
891 Hz
1120 Hz
1414 Hz
PERCENT OF TIME

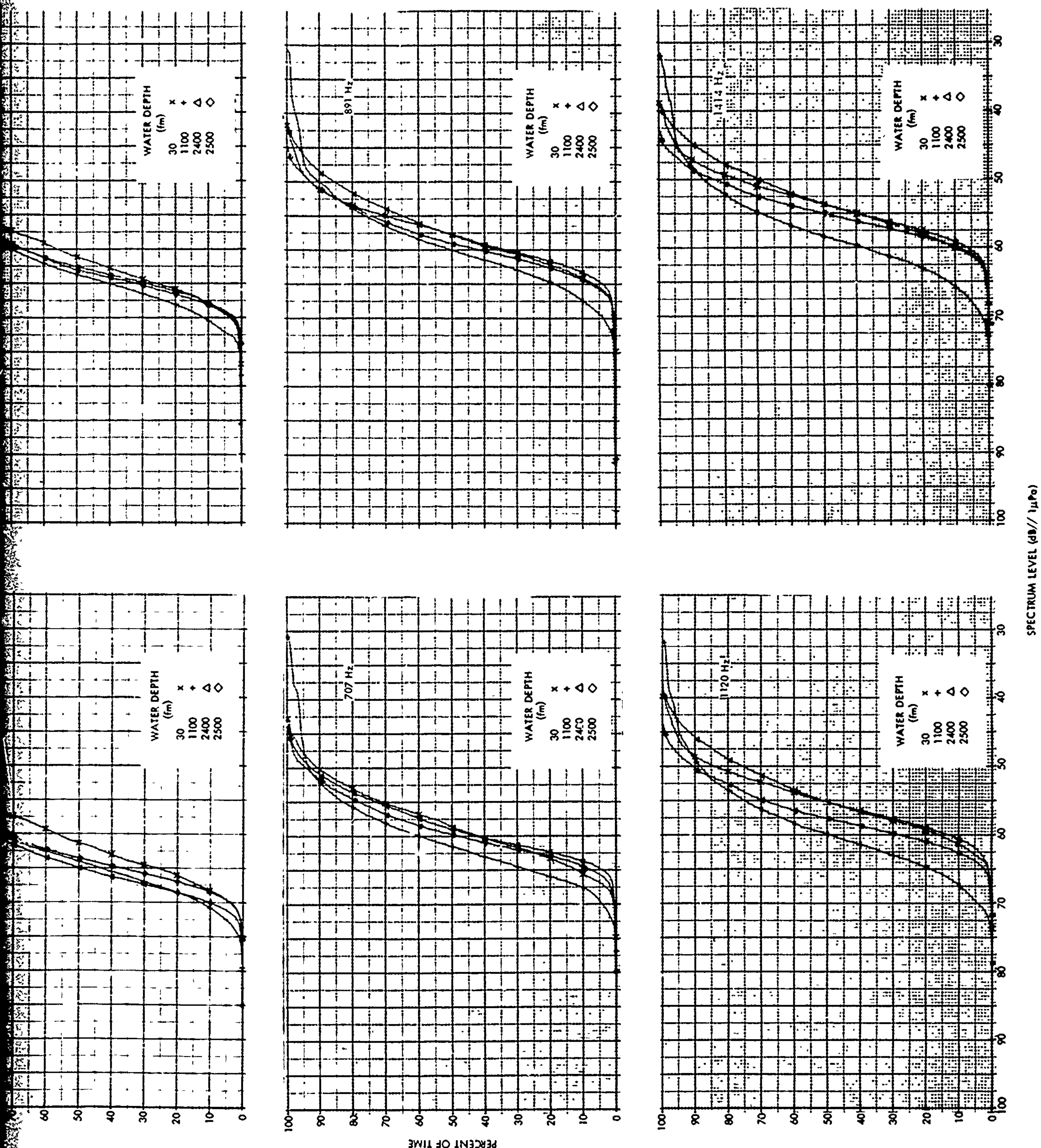


Figure 15. Cumulative Distribution of Ambient Noise Level for 22 Frequencies at 5 Hydrophone Depths

VI. CROSSCORRELATION OF AMBIENT NOISE LEVEL WITH WIND SPEED

In order to provide a quantitative measure of the dependence of ambient noise upon wind speed, time histories of noise and wind speed were sampled every two hours and cross correlated. This was done for each monthly period and for the entire year for each frequency band and receiver depth. The results were normalized by the maximum values and plotted in figures 16 through 19. Figure 16 shows the monthly variation in coefficient values for 7 selected frequencies and for each hydrophone depth. Figure 17 shows the same coefficient values replotted for the same frequencies for each of the 12 months to show their variations as a function of depth. Figures 18 and 19 illustrate crosscorrelation coefficients based on the entire year of data showing their variations as a function of frequency (figure 18) and, for selected frequencies, as a function of hydrophone depth (figure 19) on a month-to-month basis. No identifiable pattern in the variations of the correlation coefficient over the entire year that could be attributed to the monthly variations in the wind speed pattern is observed in figure 16 for hydrophone depths greater than 400 fm (730 m).

The correlation values shown for all bands between 89 and 1414 Hz as a function of the month for the 30 fm (55 m) hydrophone appear to be directly dependent on the monthly wind speed pattern as shown in figure 7. The lack of wind speed patterns for the deeper hydrophones is probably affected by variations in the combined shipping and wind speed fluctuation distributions as a function of the month. The most significant pattern observed in the crosscorrelation coefficient values as a function of hydrophone depth in figure 17 is the decreasing values of correlation from the 30 fm (55 m) hydrophone to the deeper ones and for the 89 and 281 Hz bands from July through December. The correlation coefficient is shown to be highest at the 30 fm (55 m) hydrophone and decreases for some frequencies and for some of the months at the deeper hydrophone depths. The coefficient values are, as shown in figure 18, highest in the very lowest and very highest bands, as would be expected from the results discussed previously. In the mid-frequency range, the correlation coefficient increases from the non-wind dependent frequencies to the higher wind dependent frequencies; i.e., from 212 to 1414 Hz the coefficients are essentially the same.

Figure 19 shows the relatively constant and higher correlation coefficients as a function of frequency for the 30 fm (55 m) hydrophone compared to the variation in the correlation coefficients observed as a function of frequency for the deeper hydrophones. This is probably because the shallow hydrophone was located such that propagation from distant sources was poor. Consequently, wind speed effects become more prominent at the shallower hydrophones. The results suggest that such a site might be considered an area in the open ocean, shielded from long distant shipping noise, and affected only by wind speed.

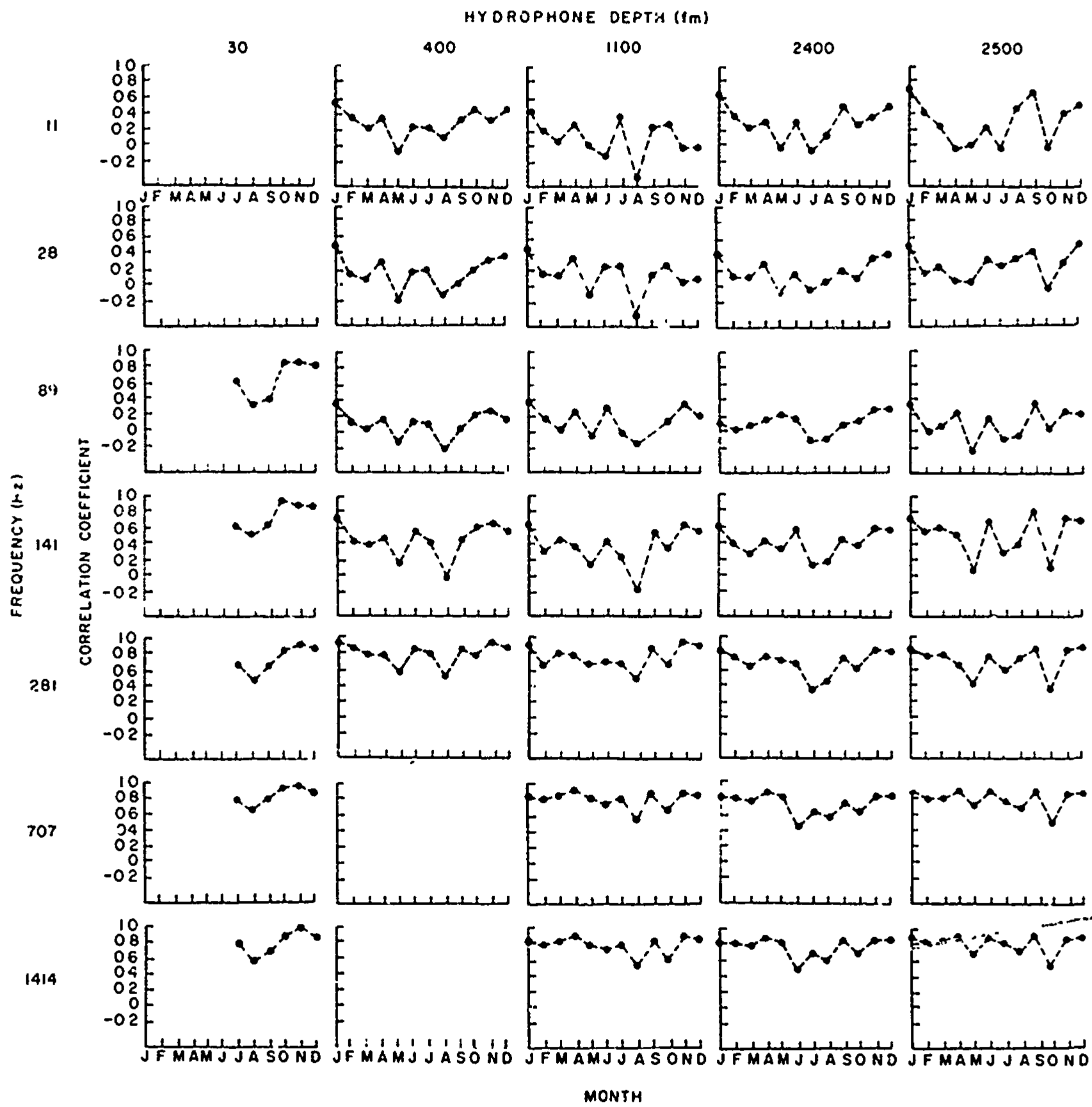
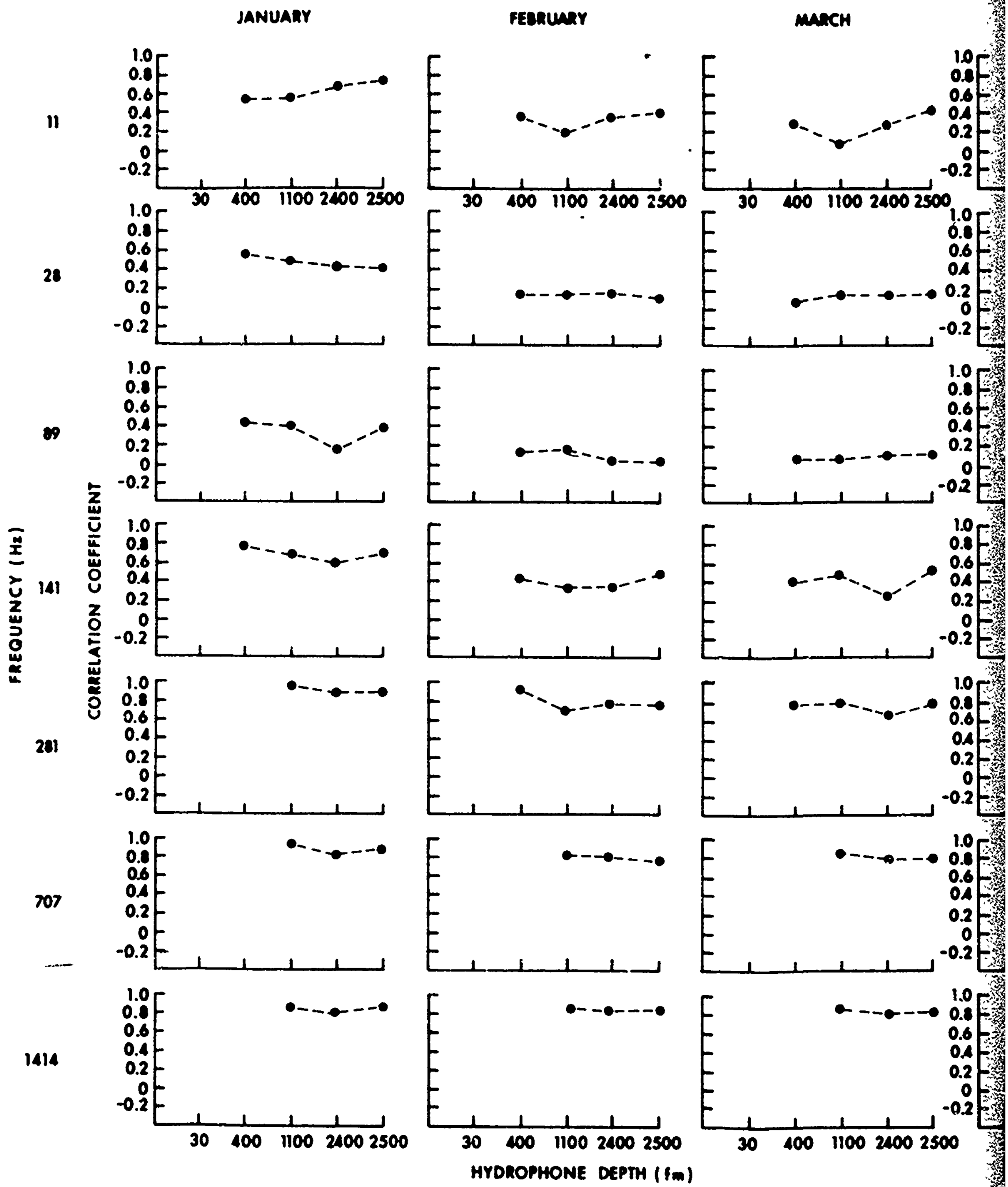
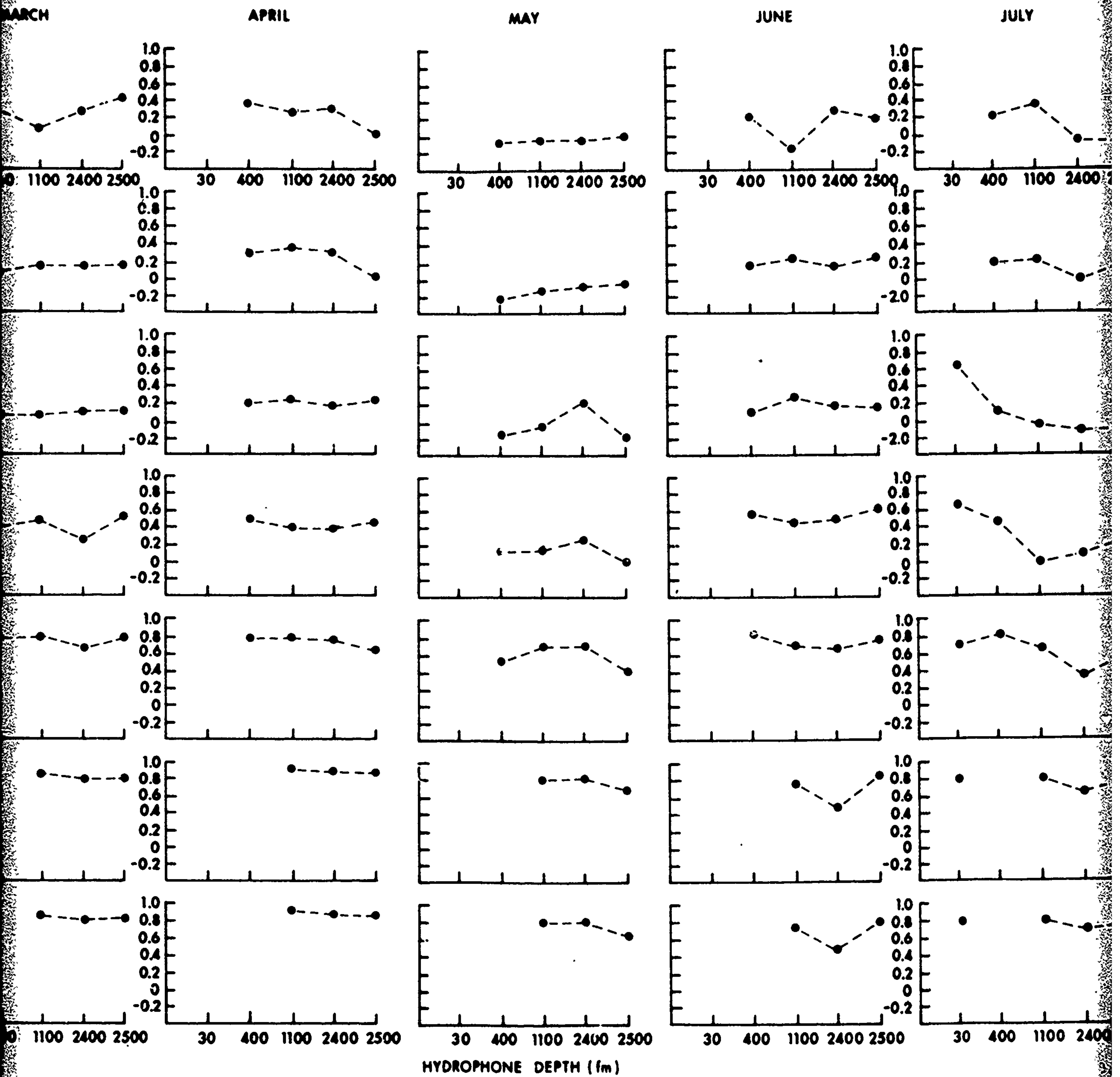


Figure 16. Monthly Crosscorrelation Coefficient Values of Ambient Noise with Wind Speed for 7 Logit Bands and 5 Hydrophone Depths



JANUARY
FEBRUARY
MARCH
FREQUENCY (Hz)
CORRELATION COEFFICIENT
11
28
89
141
281
707
1414
1.0
0.8
0.6
0.4
0.2
0
-0.2
30
400
1100
2400
2500
HYDROPHONE DEPTH (fm)



MARCH
APRIL
MAY
JUNE
JULY
1.0
0.8
0.6
0.4
0.2
0
-0.2
-2.0
30
400
1100
2400
2500
HYDROPHONE DEPTH (fm)

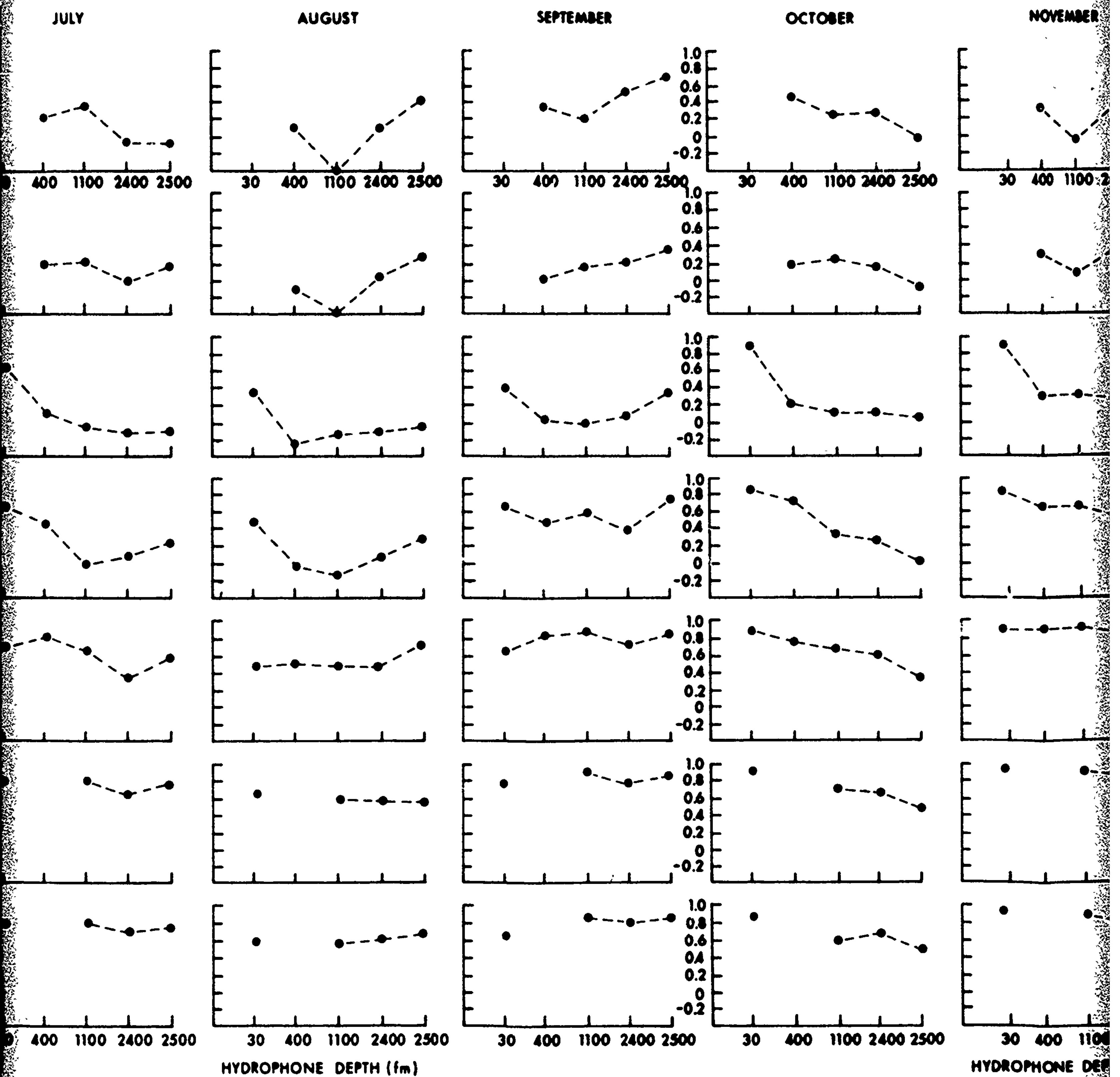


Figure 17. Crosscorrelation Coefficient Values of
for 5 Hydrophone Depths for 7 Logit Bands

3

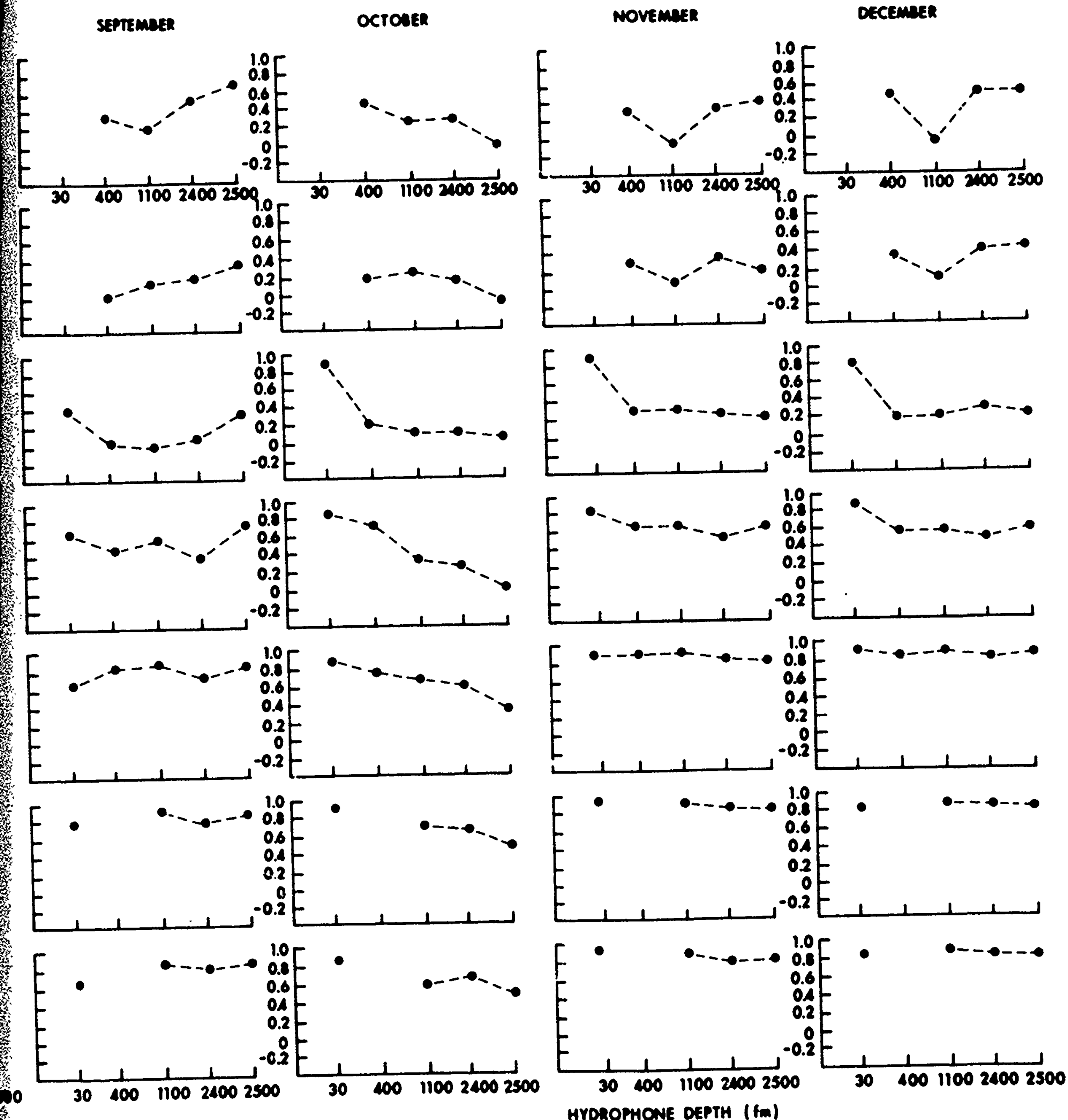


Figure 17. Crosscorrelation Coefficient Values of Ambient Noise with Wind Speed for 5 Hydrophone Depths for 7 Logit Bands for each Calendar Month

4

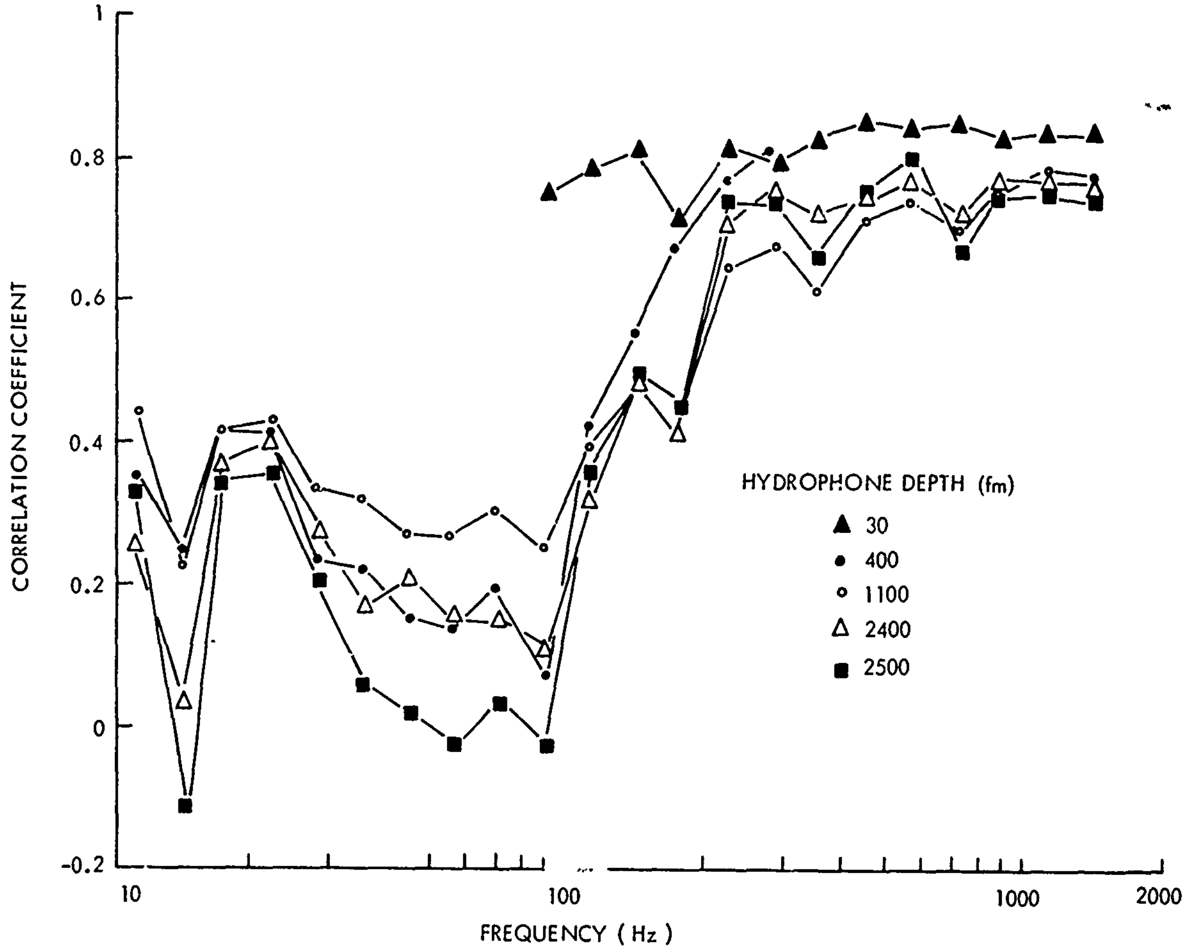


Figure 18. Crosscorrelation Coefficient Values of Ambient Noise as a Function of Frequency for 5 Hydrophone Depths

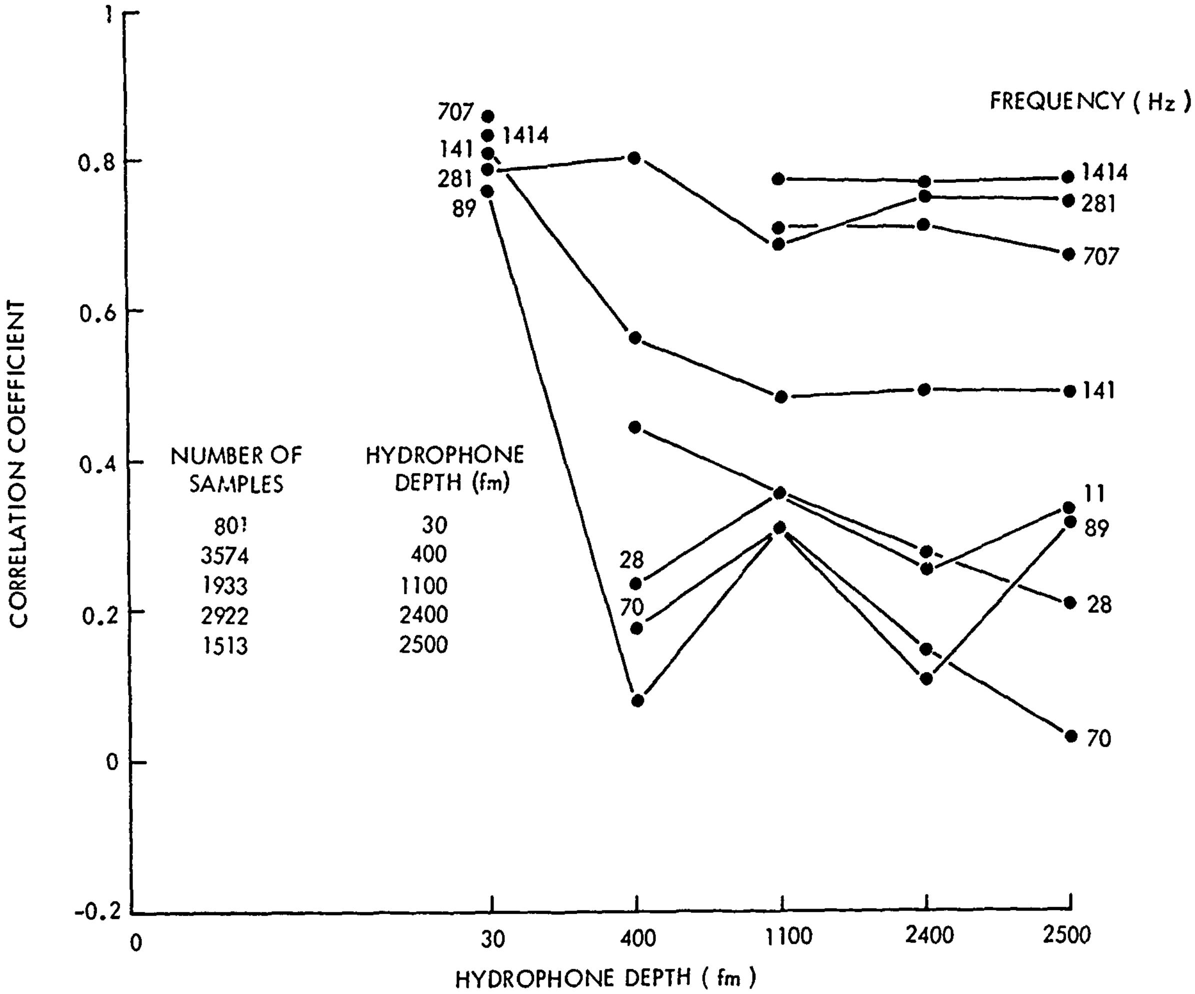


Figure 19. Crosscorrelation Coefficient Values of Ambient Noise as a Function of Hydrophone Depth for 9 Frequencies

VII. ZERO-AXIS CROSSING TIMES OF THE AUTOCORRELATION FUNCTION FOR WIND SPEED AND AMBIENT NOISE LEVEL TIME SERIES

Zero-axis crossing times[3] of the autocorrelation function for the wind speed time series and ambient noise level time series were obtained for wind speed and ambient noise data for each of the logit bands. The zero-axis crossing results shown in figure 20 were plotted on a monthly basis for wind speed data only. The pattern generated from the monthly zero-axis crossing times shown in figure 20 indicates that monthly wind speed data for the Bermuda area are within two distinct time-constant groups. One time constant, ranging from 22 to 30 hr, represents the wind condition for winter months and the other, longer, time constant of 36 to 40 hr represents the summer months. Consequently, results of the zero-axis crossing times of the autocorrelation function for the monthly ambient noise level time series (for 2400 fm (4400 m) data only) were grouped into either characteristically summer or winter. data and are plotted versus frequency in figure 21.

In general, the overall results for the summer and winter months are similar (zero-axis crossing times for the summer months are slightly higher than for the winter) and show that the total ambient noise spectra fall within two distinct zero-axis crossing times. One time zone, above 212 Hz, has relatively constant zero-axis crossing times; i.e., averaging values of 28 hr during winter months and 32 hr during summer months. These zero-axis crossing times are in good agreement with those of the wind autocorrelation function. The other zone, below 141 Hz, contains lower zero-axis crossing times ranging from an average value of 12 hr during winter months to 15 hr during summer months; it represents the shipping zone. The transitional zone is represented by the slope of the data curve for frequencies between 141 and 282 Hz where the ambient noise signal is a composite of wind and ship generated noise sources.

---

[3] A. J. Perrone and L. A. King, "Analysis Technique for Classifying Wind- and Ship-Generated Noise Characteristics," Journal of the Acoustical Society of America, vol. 58, 1975, pp. 1186-1189.

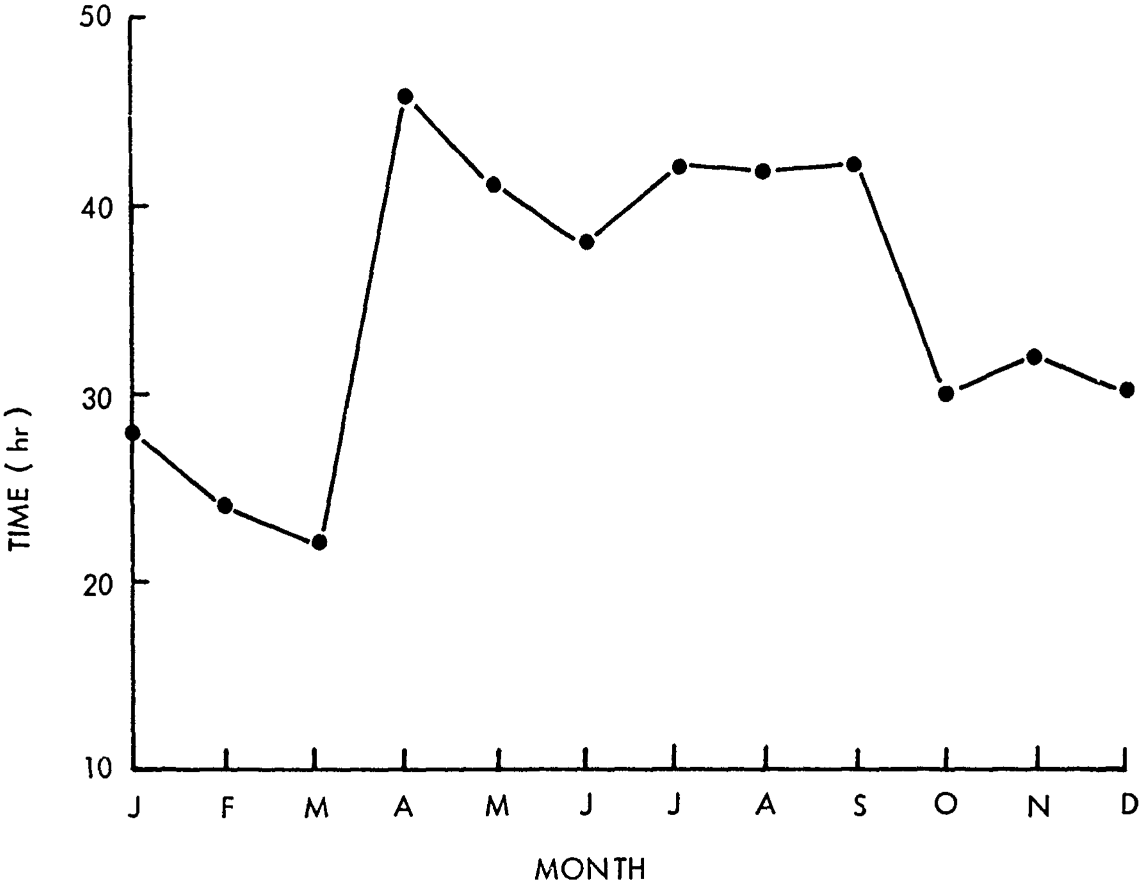
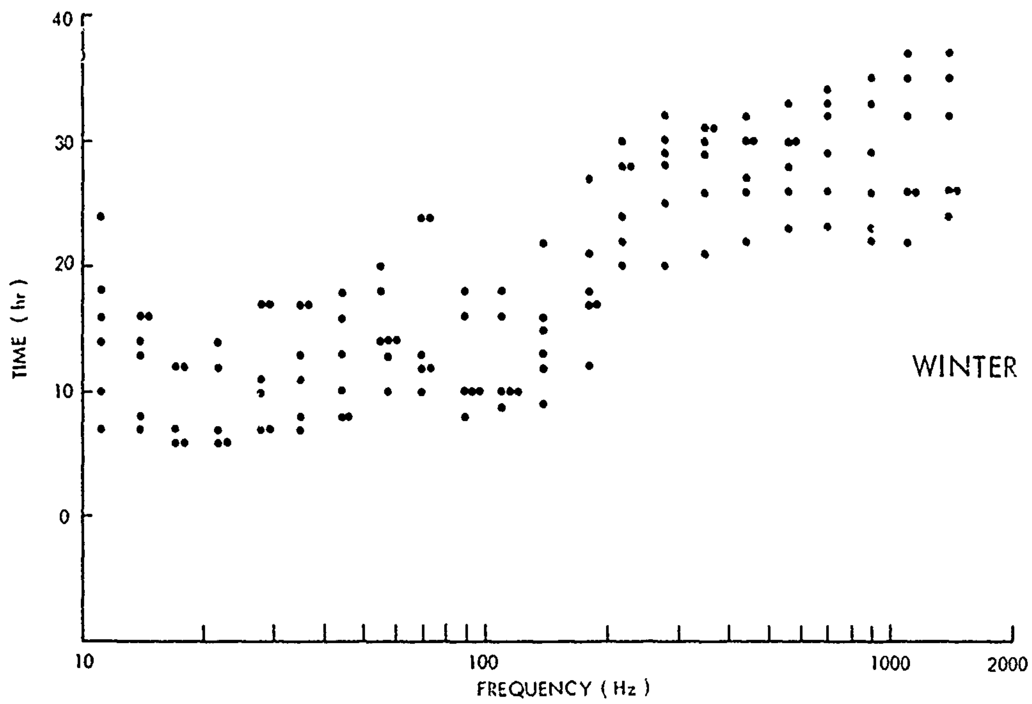


Figure 20. Zero-Axis Crossing Times of the Autocorrelation Function of Wind Speed for Each Calendar Month



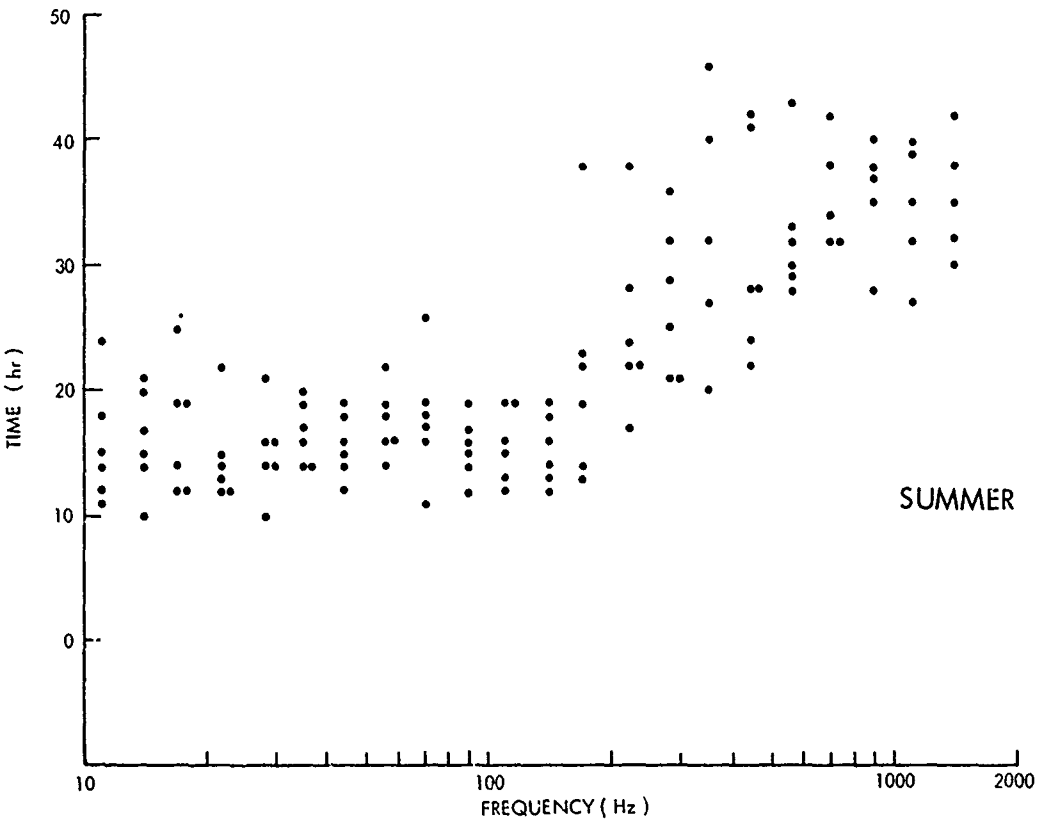


Figure 21. Zero-Axis Crossing Times of the Autocorrelation Function of Ambient Noise for Each Calendar Month Versus Frequency (Data Grouped for Summer and Winter Months)

VIII. AMBIENT NOISE LEVEL DEPTH DEPENDENCE

Seasonal variations in the mean ambient noise spectra level as a function of depth are plotted in figure 22 for 9 frequencies during January, April, July, and October. More detailed plots, showing the dependence of ambient noise levels as a function of depth for 4 wind speed groups using frequency as the parameter are shown in figures 23 and 24. The data in figure 25 were plotted using hydrophone depth as the parameter. Except for the level difference resulting from different wind speed conditions during the various times of the year, the slopes of the depth curves in figure 22 are relatively parallel to one another and, as a result, no significant change in level at each of the hydrophone depths appears to occur as a function of season. In figures 23 through 25 the mean ambient noise spectrum levels for the entire year of data are plotted for the 5 hydrophone depths of 30, 400, 1100, 2400, and 2500 fm (55, 730, 2000, 4400, and 4500 m). At each depth, the average value of the ambient noise is plotted for 9 selected frequencies between 11 and 1414 Hz.

The dependence of ambient noise levels as a function of depth is shown in figure 23 for 4 wind speed groups between 0 and 52 knots. The overall results show a depth dependence in the ambient noise level as a function of wind speed (figure 23), hydrophone depth (figure 24), and frequency (figure 25). The variations in ambient noise levels as a function of depth shown in figure 23 produce a triangular shaped pattern, which illustrates the changing spectrum slopes as a function of depth. The changing spectrum slope and the ambient noise level depth dependence are probably caused by the two major directional noise sources existing in the open ocean. One source is sea surface and is generated by local wind speed conditions; the second is generated by long distance shipping. The lower values of ambient noise levels at frequencies below 281 Hz for the 30 fm (55 m) hydrophone is, again, the result of poor propagation from distant sources. It is these sources that are major noise contributors in the lower frequency bands and, consequently, the noise levels are observed to be much lower. The levels measured at these frequencies for the 30 fm (55 m) hydrophone is wind speed dependent only, whereas, for the deeper hydrophone depths, the received wind speed noise levels are dominated by the higher noise levels produced by long distant shipping.

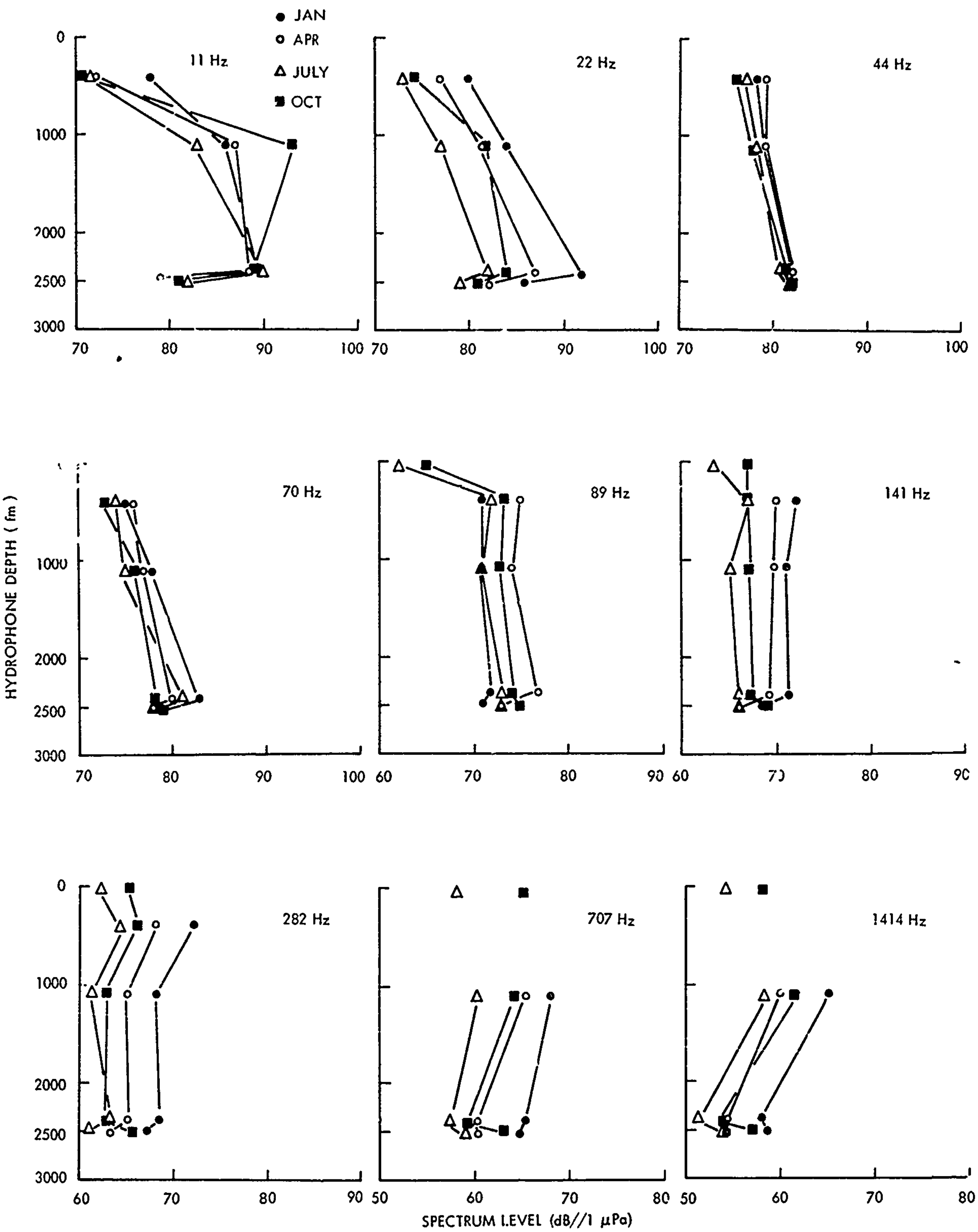


Figure 22. Ambient Noise Level Versus Hydrophone Depth for Four Seasons at 9 Frequencies

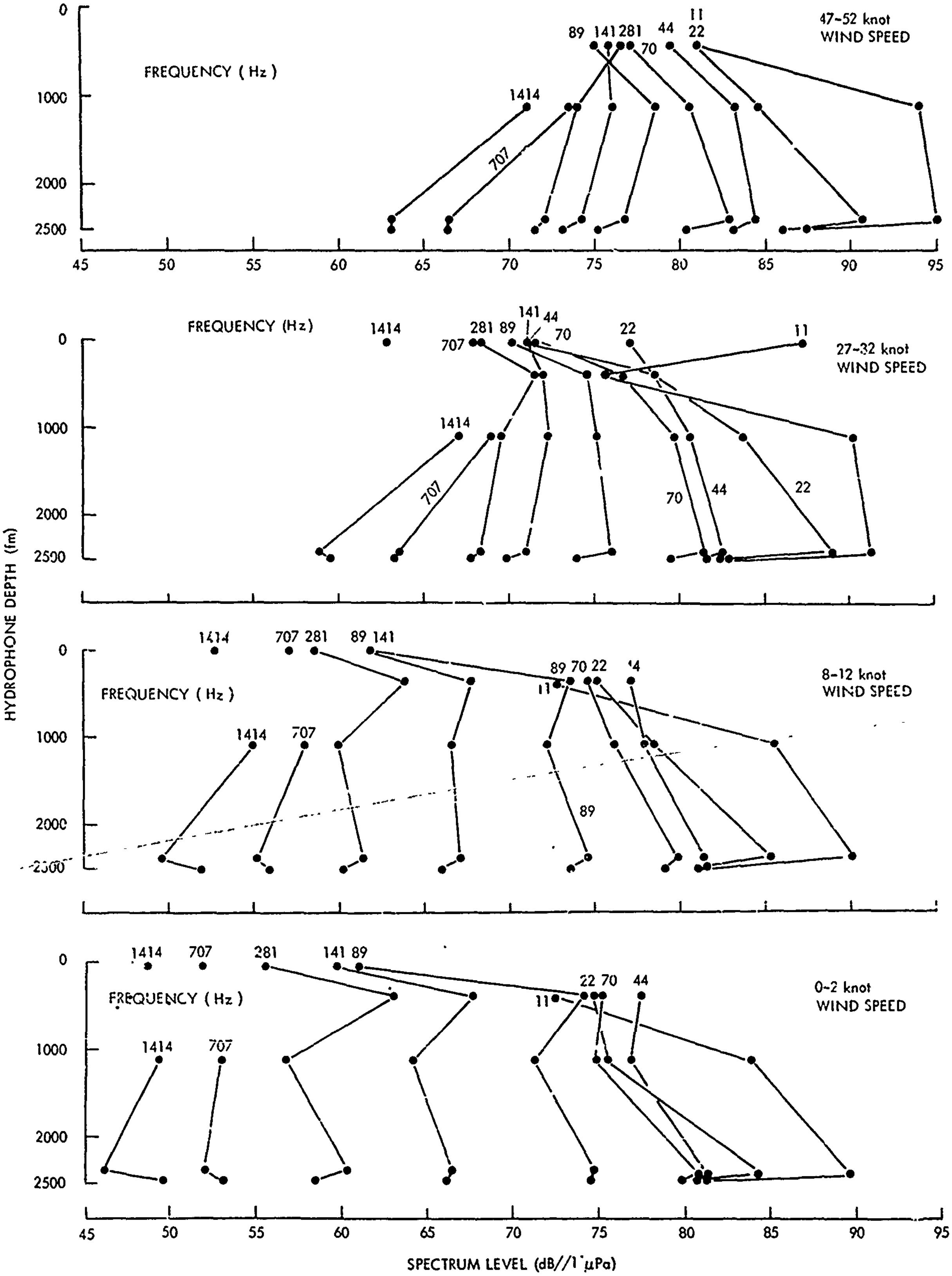


Figure 23. Ambient Noise Level Versus Hydrophone Depth for 9 Frequencies and 4 Wind Speed Groups

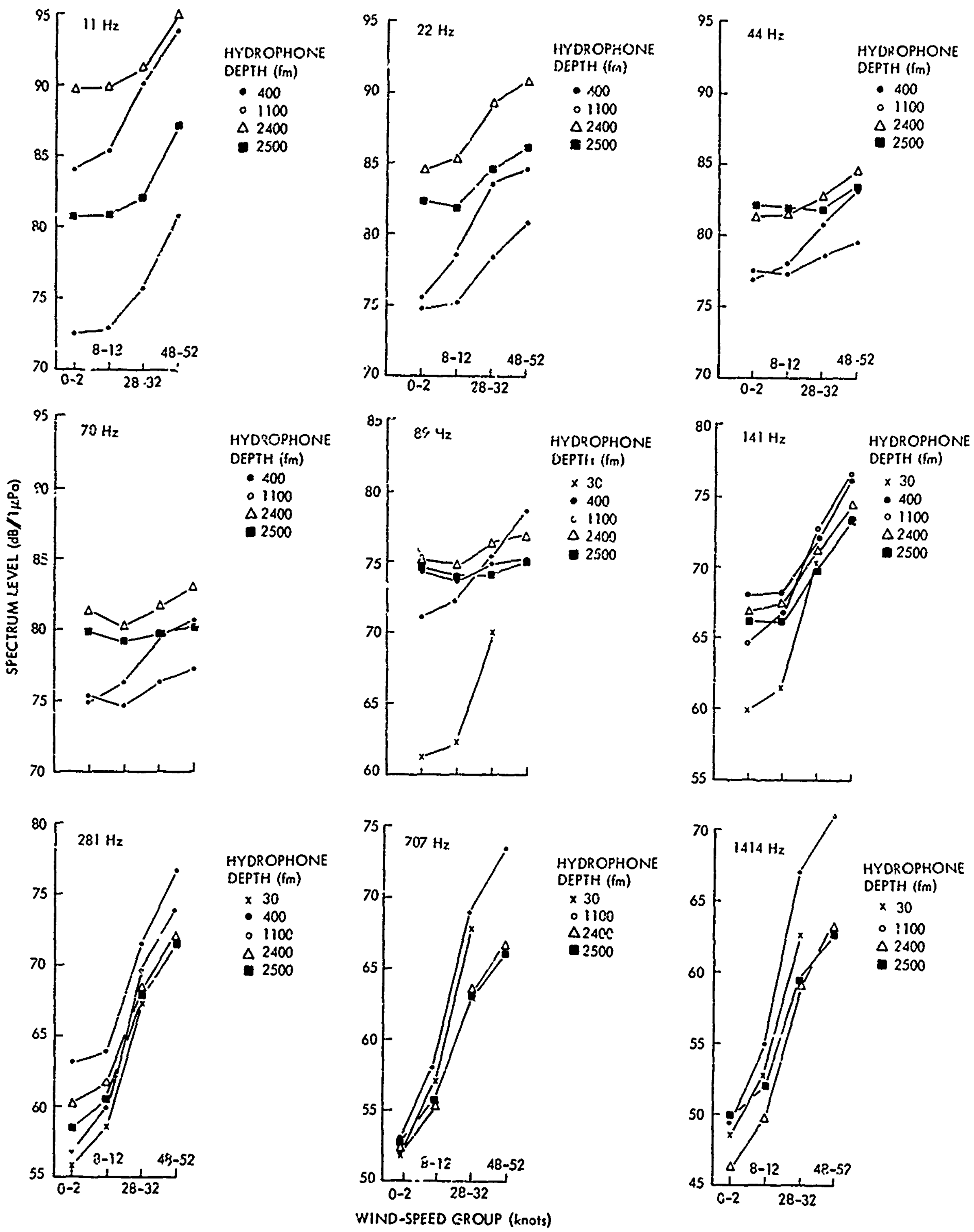


Figure 24. Ambient Noise Level Versus 5 knot Wind Speed Groups for 5 Hydrophone Depths and 9 Frequencies, Data Grouped by Hydrophone Depth

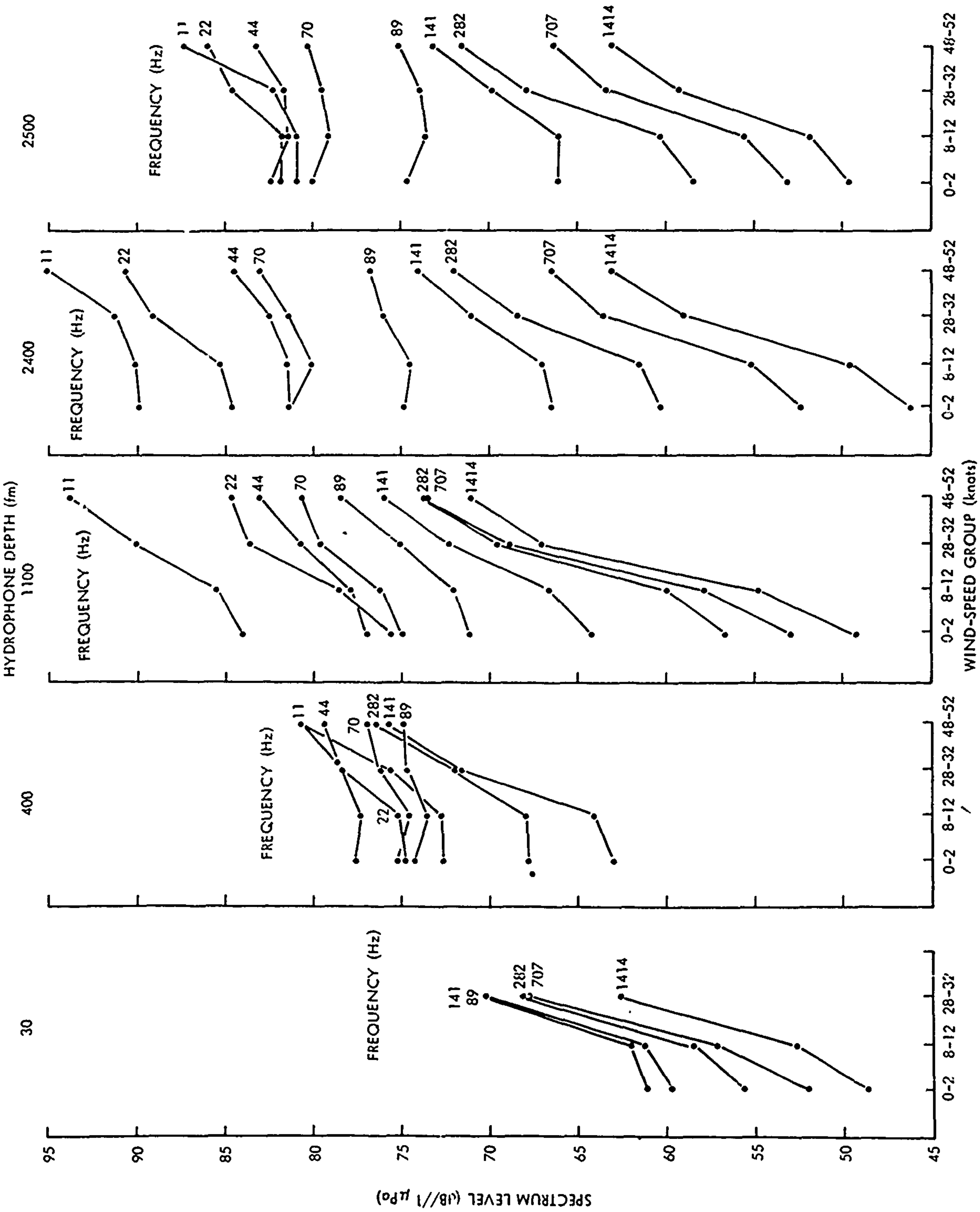


Figure 25. Ambient Noise Level Versus 5 knot Wind Speed Group for 5 Hydrophone Depths and 9 Frequencies, Data Grouped by Frequency

IX. STANDARD DEVIATION VERSUS HYDROPHONE DEPTH

The standard deviation of the ambient noise data for 3 wind speed groups (i.e., data corresponding to records whose associated wind speed values fall within those three ranges) for the entire year of data are plotted in figure 26 as a function of frequency for each hydrophone depth. The 5 hydrophone depths were 30, 400, 1100, 2400, and 2500 fathoms (55, 730, 2200, 4400, and 4500 m). The 3 wind speed groups selected were 3 to 8 knots, 18 to 23 knots, and 38 to 43 knots. The overall results show that the standard deviation of the ambient noise data is weakly proportional to hydrophone depth. In additon, the standard deviations are dependent on wind speed. For the high wind speed group (38 to 43 knots), the variations in the standard deviation remain relatively constant at approximately 1 dB over the 10 to 1414 Hz range. In the lowest wind speed group (3 to 8 knots), the standard deviation varies from approximately 1 dB in the lowest band to a peak of 5.5 dB at 1100 Hz. In the 18 to 23 knot wind speed group, the standard deviation curve has the same qualitative behavior as that of the highest wind speed data but its average value is approximately 2.3 dB. The variance in the mean values of the sound pressure spectrum levels as a function of frequency at wind speeds below 23 knots is interpreted as resulting from the superposition of a wind-dependent and a nonwind-dependent source.

The portion of the variation in the ambient noise data attributed to wind-dependent sources is believed to be quite small and relatively invariant over the entire frequency range of interest. This would account for the small constant standard deviations that are found at high wind speeds. On the other hand, the portion caused by shipping is not constant and depends on the amount, type, and location of ocean traffic; consequently, the noise received may vary, [illegible] The variation will increase with increasing frequency because the greater attenu[illegible] of noise in the upper bands limits the extent of the geographical area in which co[illegible]uting sources may be present and, hence, the total number of such sources.

Qualitatively, it may be said that the shipping noise in the lower bands that reaches the receiving hydrophones is the result of the superposition of noise fields associated with a large number of widely distributed sources. The contributions of these sources to the total noise field are relatively less dependent upon the range and location of the individual sources. At higher frequencies, the noise field at the receiving hydrophone is more dependent upon propagation conditions and the location of relatively fewer sources at shorter distances.

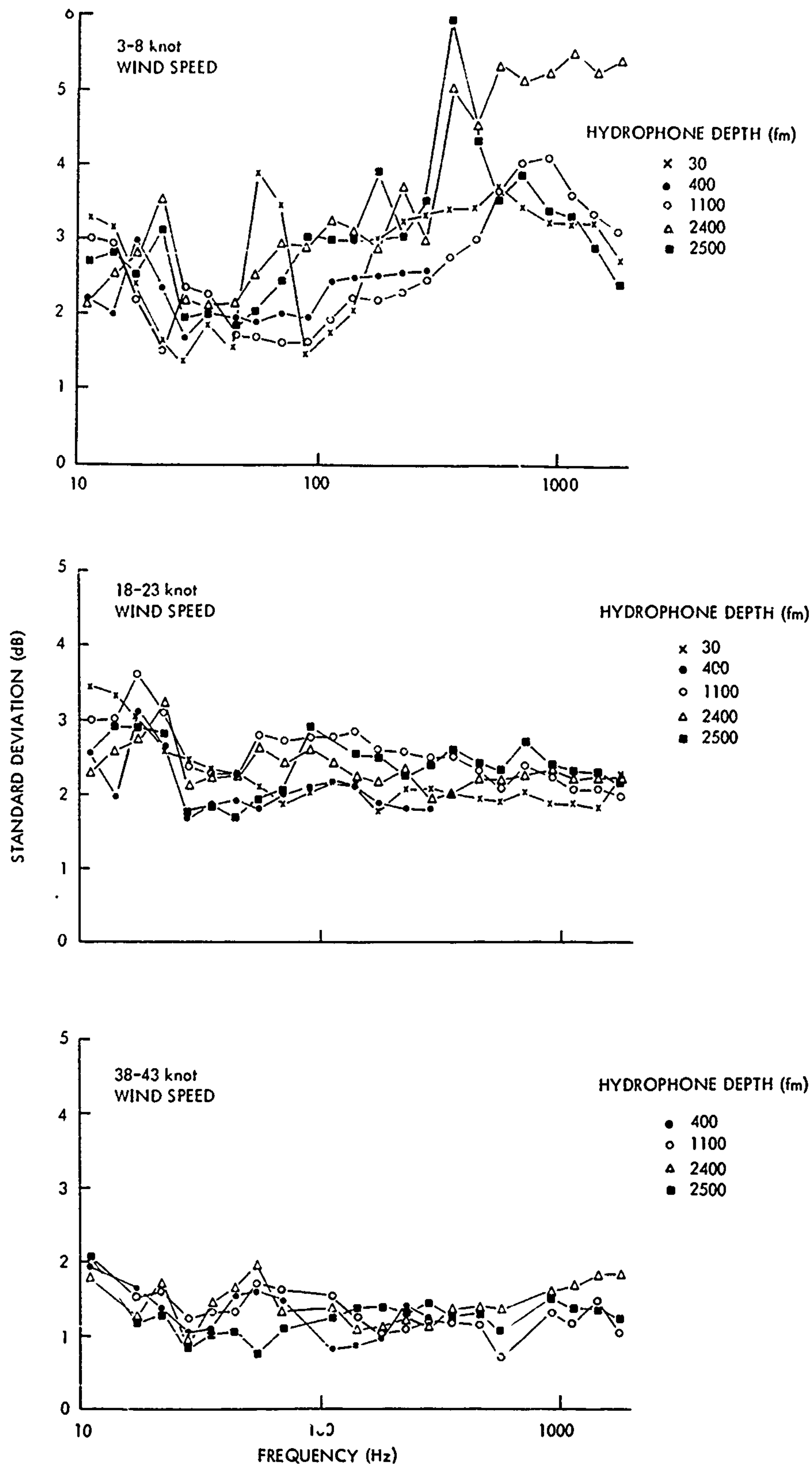


Figure 26. Standard Deviation of Ambient Noise Level for 5 Hydrophone Depths and 3 Wind Speed Groups

X. WIND SPEED AND WAVE HEIGHT DISTRIBUTIONS

Wind speed and wave height data were recorded at 2 hr intervals during the year. From these data (approximately 4000 points) histograms of cumulative distributions, the median values of wind speed (with quartiles), and the median values of wave height were computed for each calendar month. Figure 27 illustrates monthly histograms of the wind speed distribution in 5 knot wind speed groups; also shown are the total number of samples per group for wind speeds ranging from 0 to 52 knots. Cumulative wind speed distributions for each month are presented in figure 28. The median values of wind speed showing the upper and lower quartiles (indicated by the vertical lines) were computed on a monthly basis and are denoted by the top curve in figure 29; the lower curve is the expected median wave height value for the median wind speed for each calendar month. The highest monthly median wind speed (22 knots) was in January and the lowest (7 knots) was in August. May through September are characterized by significantly lower wind speeds than are the others. The overall median wind speed curve and the median wave height curve for the entire year are observed to be quite similar in shape, as expected. The relationship of the average wind speed to average wave height for 1 knot wind speed increments were also computed from these data; the results are shown in figure 30.

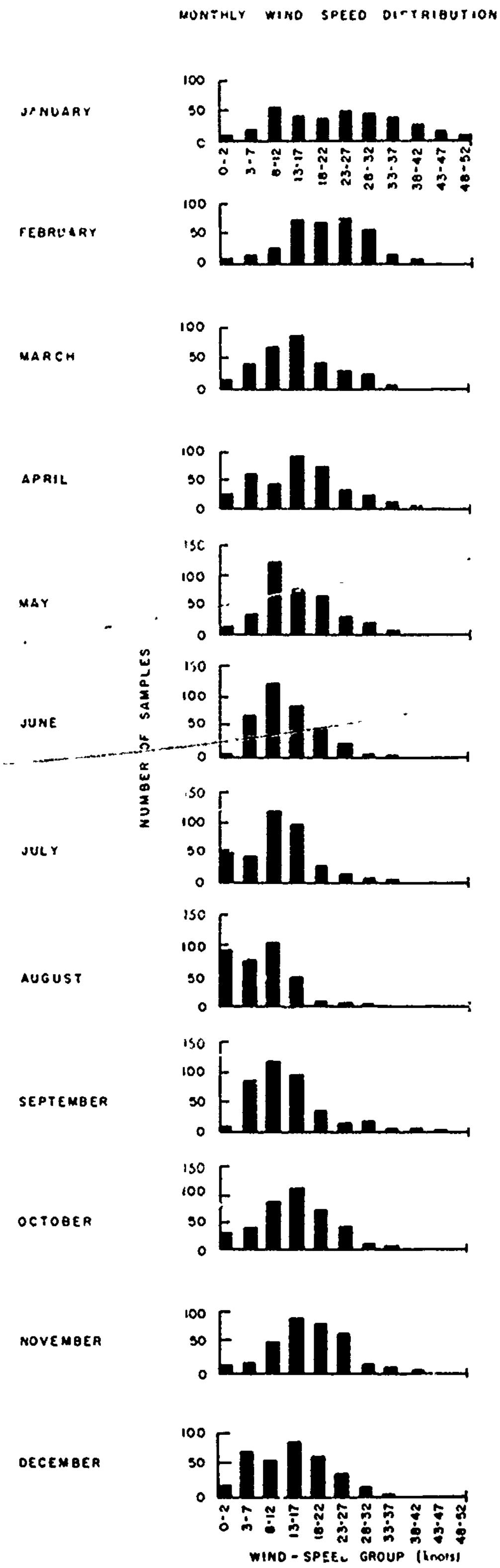


Figure 27. Monthly Histograms of Wind Speed for 5 knot Wind Speed Groups

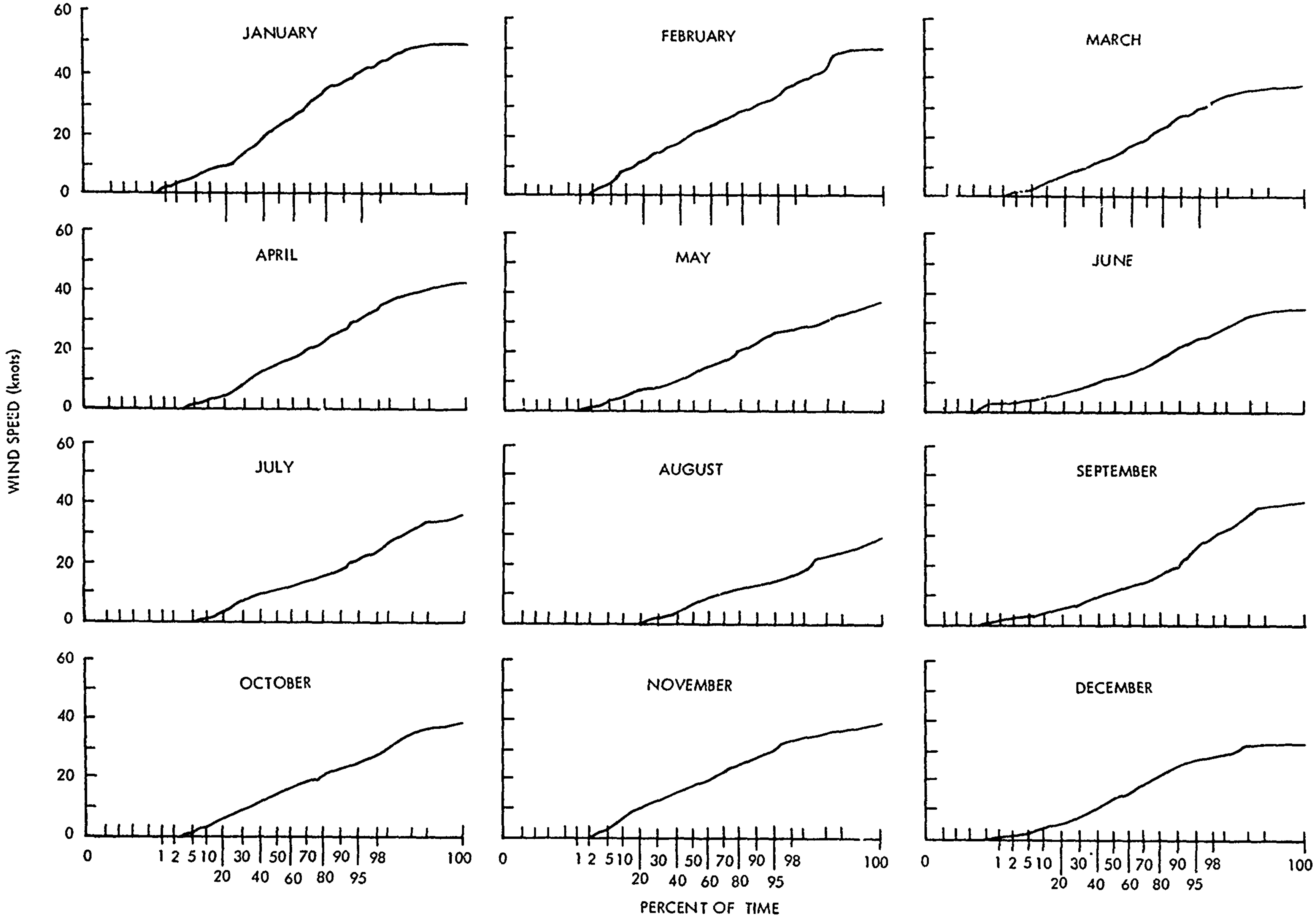


Figure 28. Monthly Cumulative Wind Speed Distribution

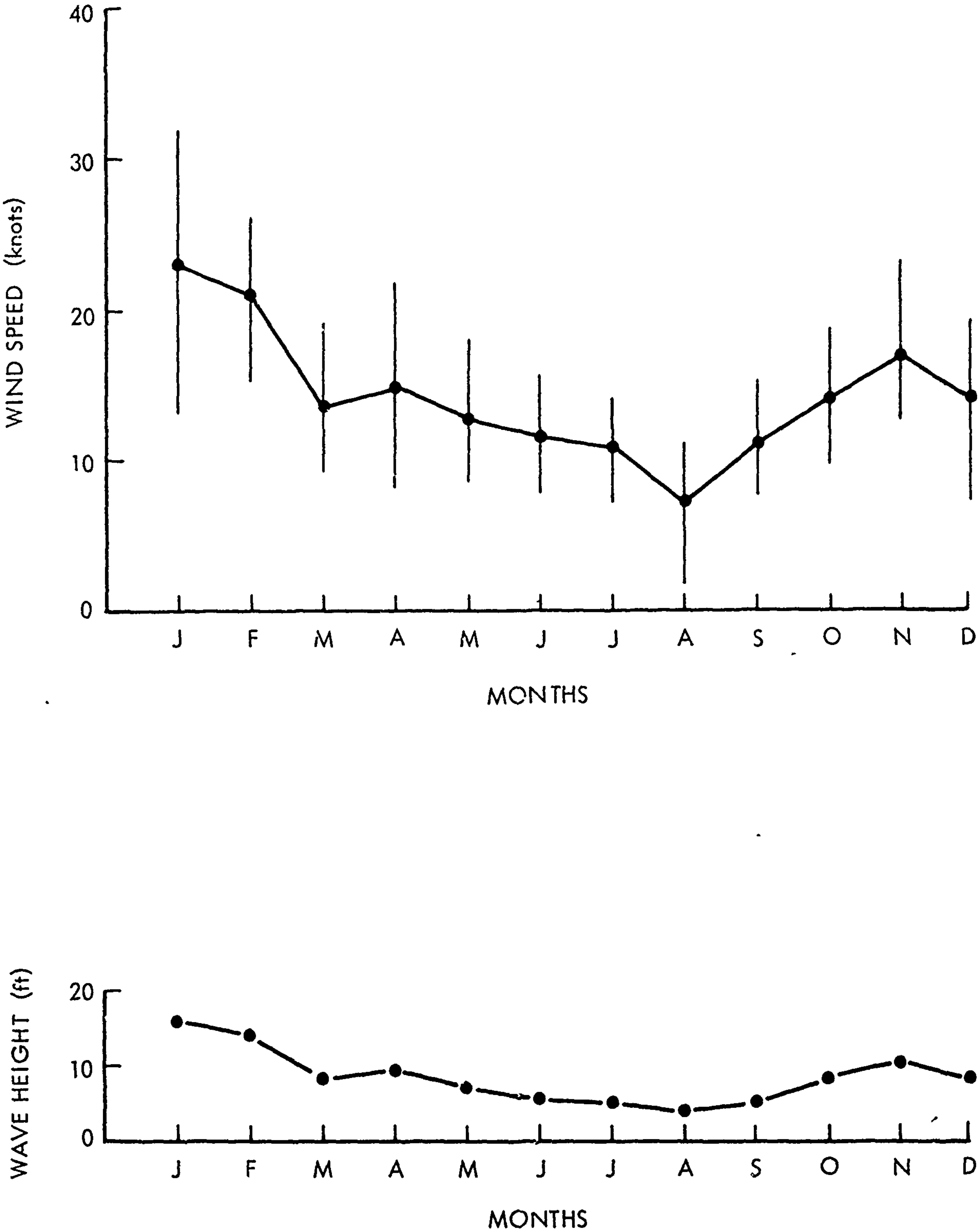


Figure 29. Monthly Median Wind Speed Showing Upper and Lower Quartile Values and Monthly Median Wave Height

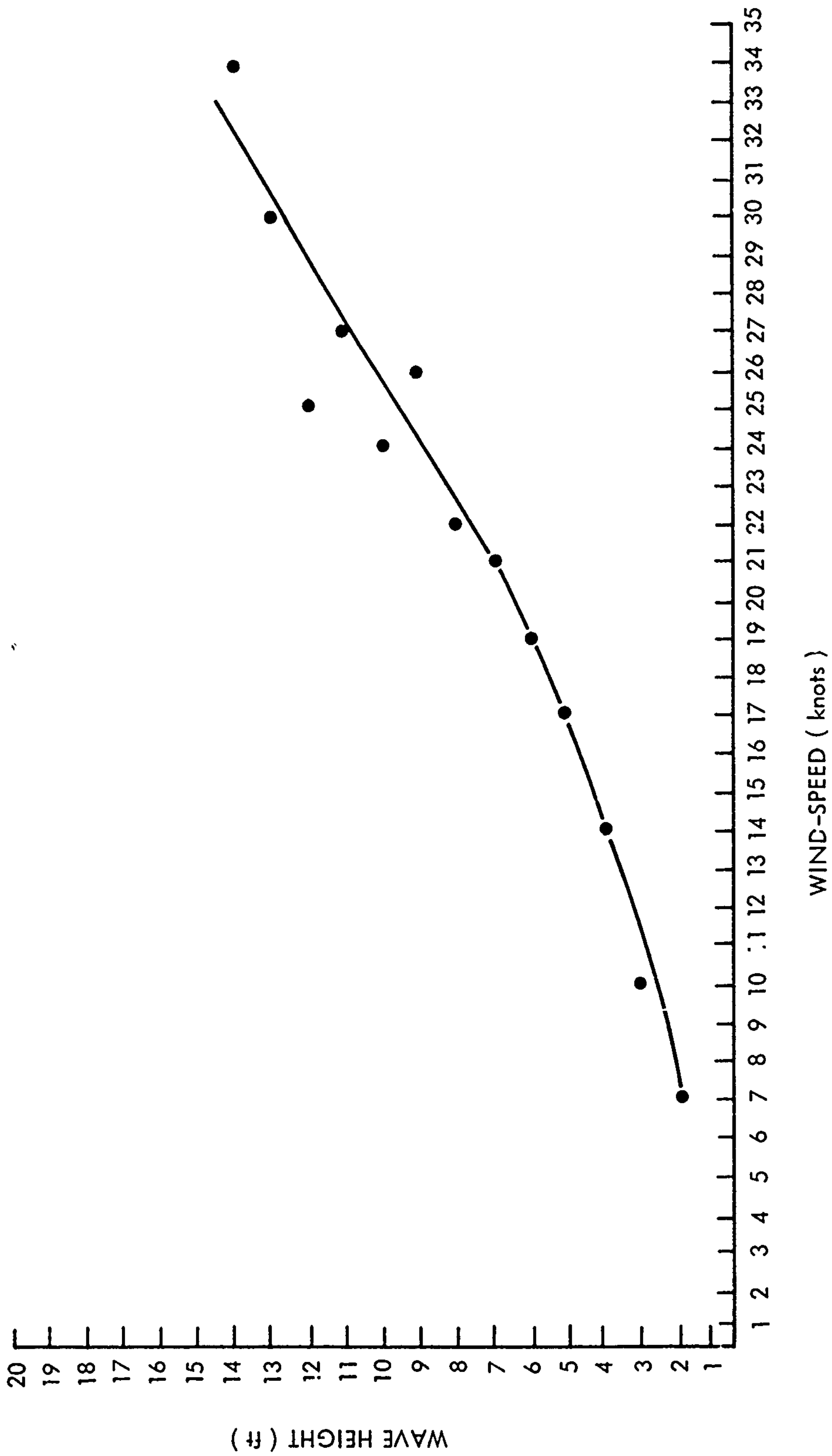


Figure 30. Average Wave Height Versus Wind Speed

XI. SUMMARY

The results of ambient noise data recorded simultaneously during a one year period between January and December 1966 from 5 hydrophones located in the Northwest Atlantic at depths of 30, 400, 1100, 2400, and 2500 fm (55, 730, 2200, 4400, and 4500 m) have been presented. All hydrophones were bottom mounted except those at 1100 and 2400 fm (2000 and 4400 m), these were suspended 60 and 400 ft (18 and 120 m), respectively, above the bottom. The broadband ambient noise levels from the 5 hydrophones were sampled every 2 hr for 2 min periods. The results show a dependence in the ambient noise spectrum levels as a function of depth, frequency, and wind speed. The shallow hydrophone (at 30 fm or 55 m) was more wind dependent than the deeper ones, especially at frequencies below 281 Hz. Consequently, the crosscorrelation coefficient value of ambient noise level with wind speed for bands between 89 and 281 Hz is shown to be highest for the shallow hydrophone. This is probably because the shallow hydrophone was located on the bank and propagation from distant sources was poor. Consequently, the effect of wind speed is more prominent for frequencies below 281 Hz at the shallow hydrophone.

Above 281 Hz, the correlation coefficient of the ambient noise spectrum levels with wind speed is observed to be essentially independent of water depth for all 5 hydrophones. No significant seasonal effects on the mean values of the ambient noise levels is observed as a function of depth, except for differences in level caused by the wind speed conditions existing during the different seasons. The standard deviation of the ambient noise signal is dependent on wind speed and weakly dependent on water depth. Variations in ambient noise levels as a function of depth produce a triangularly shaped pattern that shows an increasing spectrum slope with increasing water depth. The spectrum slope as a function of depth varies with wind speed. The difference in ambient noise level between hydrophone depths as a function of frequency is suspected to be the result of the two major directional noise sources existing in deep ocean areas. One of these noise sources yields a signal that arrives from a nearly vertical direction and is generated by local wind speed conditions that affect the frequency range above 177 Hz, where ambient noise spectrum levels decrease with increasing depth. This decrease in level as a function of depth becomes larger with increasing frequency.

The other noise source yields a signal that arrives from the horizontal direction and is generated by long distance shipping; this source affects the frequency range below 177 Hz. The ambient noise signals in this range arrive at the receiver via the RSR and RRR paths. The results obtained from the autocorrelation of the ambient noise data for each logit band between 11 and 1414 Hz indicates that there are two zero-axis crossing times for the autocorrelation function versus frequency. One zone, above 212 Hz, shows an average zero axis crossing time of 30 hr (wind dependent zone) and the other, below 141 Hz, has zero axis crossing times of approximately 12 hr (shipping dependent zone).

INITIAL DISTRIBUTION LIST

Addressee	No. of Copies
COMASWFORSIXTHFLT	1
COMNAVSURFLANT	1
COMNAVSURFPAC	1
COMSUBLANT	1
COMSUBPAC	1
COMOPTEVFOR	1
COMSUBDEVGRUONE	1
COMSUBDEVGRUTWO	1
ASN (R&D)	2
ONR, (Code 102-OS, -412-8, -412-3, -480, -481, -484, -485, -410)	8
NORDA	1
LRAPP (Code 102-OSC)	1
CNO, (Op-095, -098, -098T, -954, -96, -96C, -981, -981F, 981G, -981H	10
CNM, (MAT-03, ASW-14, -22, -23, -24)	5
DDR&E (G. Cann)	2
NAVSHIPRANDCEN, ANNA	1
NAVSHIPRANDCEN, CARD	1
NRL	2
OCEANAV	1
NAVOCEANO, (Code 02, -7200, -9320)	3
NAVELECSYSCOMHQ, (Code 03, -320, PME-124)	3
NAVSEA, (SEA-03C, -0341, -06H, -06H1, -06H1-1, -06H1-3, -06H1-4, -06H2, -09G3(4))	12
NAVAIRDEVCEN	2
NAVWPNSCEN	1
DTNSRDC	2
NAVCOASTSYSLAB	1
NAVSURFWPNCEN	1
NUC	2
NAVPGSCOL	1
MARINE PHYSICAL LAB, SCRIPPS	1
ENV RES LAB (NOAA/ERL)	1
COMMITTEE UNDERSEA WARFARE	1
WEAPON SYSTEM EVALUATION GROUP	1
WOODS HOLE OCEANOGRAPHIC INSTITUTION	1
DDC	12